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ALLMAG, GDALMG, LINTRA: COMPUTER PROGRAMS FOR GEOMAGNETIC FIELD AND FIELD-LINE CALCULATIONS

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ABSTRACT

A set of computer programs has been developed for the calculation of the geomagnetic field and the tracing of field lines in space. The basic subroutine, geocentric ALLMAG, contains coefficients for seven recently-published field models as built-in data statements. At execution time the user can vary the model and/or the time period simply by changing input parameters. Subroutine GDALMG is adapted for input and output in geodetic coordinates. ALLMAG and GDALMG are equivalent to Cain's FIELD and FIELDG, with the added flexibility of the choice of seven models. LINTRA traces field lines from any point in space to a specified altitude intersect in the same or opposite hemisphere, using any of the models contained in ALLMAG. Input is in either geocentric or geodetic coordinates, and output is returned in both. McIlwain's INVAR package, which calculates B and L, has been adapted to use ALLMAG. All programs are described in detail, and sample calculations are given.

CONTENTS

APPENDICES

ALLMAG, GDALMG, LINTRA: COMPUTER PROGRAMS FOR GEOMAGNETIC FIELD AND FIELD-LINE CALCULATIONS

1. INTRODUCTION

The proliferation of quantitative geomagnetic field models in the last decade, evidently stimulated by the advent of the space age and the satellite era, has resulted in a confusing abundance of good numerical models that are based on a spherical harmonic expansion of the geomagnetic potential. Most of these models have included first- and occasionally second-order time derivatives of the spherical harmonic coefficients, giving the secular change of the field.

There has been for some time a need for a versatile, unified set of computer routines which would permit the user to choose different models and/or time periods during one execution time, in order to compare the predictions of different models or to compute the value of the field at different time periods.

In the past, when it was desired to perform field calculations with a different model or another time period, it was in many cases necessary (e.g. McIlwain's INVAR) either to replace completely the field-computing routine or to first calculate the coefficients for the new date, punch them onto cards, and then physically insert them into the model deck; this was at best an error-prone and time-consuming procedure, lacking both flexibility and efficiency.

The purpose of our effort was to devise a practical and dependable system by which these shortcomings could be overcome without sacrificing either accuracy or speed. It resulted in the creation of ALLMAG, a program package combining in one operation two previously separate functions, namely the calculation of coefficients for a given model and time period and the computation of the field vector. ALLMAG has the added advantage of incorporating seven widely used field models "under one roof," without having to read in data cards at execution time. These models, all with internal source terms only, are described in the next section. During a single execution one can successively vary either the model or time period, or both.

The spherical harmonic coefficients for the models are stored in data statements in the beginning of the program; in this respect, the code is complete and self-contained. The coefficients are tested for accuracy and renormalized the first time the subroutine is called; updated coefficients are then calculated each time a new model or time period is selected.

ALLMAG is available in a "short version" (using subscripted variables and do-loops) and a time-saving "long version," with fixed indices and functions written out in extenso, yielding identical results. The long version calculates the field vector in about a third the time as the short version, and is therefore suitable for lengthy calculations with frequent calls to the subroutine. Execution times are comparable to or faster than other programs currently available.

ALLMAG was designed as an independent, self-contained subroutine with input and output in geocentric coordinates. A short subroutine GDALMG was developed, with input and output in geodetic coordinates (geodetic latitude and altitude above the geoid), to be used in conjunction with ALLMAG. GDALMG performs all necessary transformations between geodetic and geocentric coordinates and computes declination and inclination in addition to the geodetic field components.

ALLMAG and GDALMG perform basically the same calculations as the MAGNET subroutine of McIlwain's INVAR (McIlwain 1961), as Hassitt and McIlwain's NEWMAG (Hassitt and McIlwain 1967), and as Cain's FIELD and FIELDG (Cain et al. 1968), with the added advantage of offering a choice of seven models and different time periods at execution time.

Two modified versions of ALLMAG were further developed, designed to be substituted for ALLMAG for special purposes. The first, DEKMAG, contains no built-in coefficients, but reads up to seven sets of coefficients as data cards at execution time. DEKMAG can thus accommodate new models as they become available. The second, ONEMAG, contains built-in coefficients for only one model, namely the IGRF model, and is designed for those who do not need the variety of models provided by ALLMAG.

Finally, for line-of-force integrations and for computations of field-line intersects at any altitude level, a new field-line-tracing routine LINTRA was developed, greatly improving Stassinopoulos' (1968) old LINTRA code. Designed around ALLMAG, the new LINTRA accepts initial starting positions in either geocentric or geodetic coordinates, and returns the initial position as well as the conjugate intersect in both systems.

Special features of LINTRA include: (1) input control of tracing direction, permitting field-line tracing to the opposite hemisphere or to a lower altitude in the same hemisphere; (2) computation of arc length of line segment traversed; (3) search for and retention of minimum-B equator position and magnitude, if it has been crossed; (4) internal functional determination of optimum integration step size.

All programs are written in FORTRAN IV computer language and card decks are available in either the 029 model IBM keypunch format (EBCDIC) for use with the IBM 360 series machines, or the 026 keypunch format (BCD) for other FORTRAN-compatible computers. An INVAR program (Hassitt and McIlwain, 1967) has been modified slightly so as to accept ALLMAG in place of NEWMAG. It yields identical values of B and L if used with the same model and time period. Sample calculations are given for GDALMG-ALLMAG, LINTRA, and the modified INVAR.

Complete listings are given for all programs except for INVAR (see Hassitt and McIlwain, 1967, for listings) and the long version of ALLMAG (see Cain et al., 1968, for listings of the arithmetic statements of the long version).

2. SELECTION OF MODELS

Seven geomagnetic field models were selected for inclusion into ALLMAG. Table 1 lists these models together with some of their basic characteristics. We included only models for which documentation was readily available through journal publication or otherwise; no preliminary models were included. We concentrated on the most recently-published models, although a few earlier, widely-distributed models were also included so as to enable direct comparisons with earlier subroutines. We did not include the widely-quoted Jensen and Cain model, since it contains no time-derivative terms and gives extremely poor predictions of the present-day field (see Cain and Sweeney, 1970).

Note that Table 1 gives both the epoch and the data range. The term "data range" is used here to denote the time period during which geomagnetic data were obtained to define the model. The "epoch" of a model with secular time-derivative terms is the zero of time from which Δt is calculated in order to add or subtract the time-derivative contribution to the main-field terms. Since in this sense the epoch is simply a numerical constant, it may or may not lie within the data range. All the Cain models, for example, are based on an epoch of 1960, for simplicity, even though the recent POGO models utilize data only from POGO satellites, the first of which was launched in 1965.

It is customary to set the input variable TM equal to the time period for which one wishes to calculate the field. It is generally undesirable, however, to input a time more than a few years away from the data range of a given model, since to do so requires extrapolation well outside the time period over which data was obtained to define the model. Recent studies (Mead, 1972) have shown that such large extrapolations can lead to highly unreliable and often divergent results. If we desire to predict the characteristics of the field in 1973.0, for

Table 1

Geomagnetic Field Models In ALLMAG

Model No.	Designation	Epoch	Data Range	n_{max} [1]	No. of Coefficients	Reference Earth	Documentation [2]
1	GSFC 9/65	1960	1945-1964	9	99	Oblate	Hendricks & Cain, 1966
2	GSFC 12/66	1960	1900-1965.8	10	120	Oblate	Cain et al., 1967
3	POGO 10/68	1960	1965.8-1967.9	11	143	Oblate	Cain and Langel, 1968
4	POGO 8/69	1960	1965.8-1968.4	10	120	Oblate	Cain and Sweeney, 1970
5	IGRF 1965.0	1965		8	80	Oblate	IAGA Commission 2, 1969 Cain and Cain, 1971
6	LME 1965	1965	1945-1964.5	8	80	Spherical	Leaton et al., 1965
7	USC&GS 1970	1970	1939-1968	12	168	Oblate	Hurwitz, 1970 Hurwitz & Fabiano, 1969

[1] The FORTRAN-stored NMAX = $n_{max} + 1$, to avoid zero indices.

[2] See References.

example, using a model such as POGO 10/68, whose data range is 1965.8-1967.9, it would be better to choose something like 1969.0 as a time input to the model, rather than 1973.0, which would require linear extrapolation over five years outside its data range. There are two reasons why these large extrapolations are undesirable. First, most models assume that the secular variation is linear, whereas long-term studies (Cain and Hendricks, 1968) clearly show that the secular variations are often highly non-linear and that linear extrapolations many years into the future are unreliable. Secondly, several of the models have used a relatively short time period to determine the secular time derivatives. It appears that data ranges of at least five years are necessary to clearly establish the linear trends.

Since the models contained in ALLMAG include no external sources, they yield very unreliable results beyond geocentric distances of 3-5 earth radii. Strong perturbations (10-100% or more) of the geomagnetic field are present in the outer magnetosphere. These perturbations depend on local time and season as well as solar wind conditions. Some improvement in the accuracy of field predictions at these distances can be obtained by adding the contribution of external sources predicted by a model such as Mead's (1964). An improved model of the external field based on least-squares fits to satellite magnetometer data (Mead and Fairfield, 1971), explicitly incorporating seasonal effects caused by the varying tilt of the dipole with respect to the solar wind, will soon be available.

A few comments on each model are appropriate. Model 1 (GSFC 9/65) was based mostly on surface survey data, with some additional localized satellite data from Vanguard 3 and Alouette. This model, updated to the time period 1965, was incorporated into the NEWMAG subroutine of the INVAR B-L program (Hassitt and McIlwain, 1967). Model 2 (GSFC 12/66) incorporates survey data back to 1900 and is the only model containing second time-derivative terms, thus making a quadratic fit to the secular variation. As such, it is probably the best single model fitting surface data over the period 1900-1965 (Cain and Hendricks, 1968). However, more recent models give better predictions of the current field. Model 3 (POGO 10/68) was the first model to use only satellite data (measurements of field magnitude only; no directional data included). Its data range is very short (2.1 years), and therefore its time derivative terms are rather poorly determined. With this model, the variable TM should probably be limited to the time period 1964-1969. Model 4 (POGO 8/69) is the most recently-published model from the Cain group as of this writing. Model 5 (IGRF) is now internationally-accepted as a reference field to use as a standard whenever comparisons are needed. Since it was derived from the components of many different models, no data range for it is given in Table 1. Model 6 (LME 1965) was used for the preparation of world magnetic charts for the epoch 1965.0 published by the Hydrographic Office of the British Ministry of Defence. The

British update their charts every 10 years, and a new model is not expected until 1975. The LME model is the only one included in ALLMAG whose derivation neglected the oblateness of the earth (it assumed R = 6371.2 km everywhere on the surface). Model 7 (USC&GS 1970) is the American World Chart Model for 1970, and was used to prepare the magnetic charts issued by the U.S. Naval Oceanographic Office in 1970. Models 6 and 7, based almost entirely on ground data, are probably preferable to use for predictions of the field at or near the Earth's surface. Models 3-5 would probably be preferable to use in space applications. Cain (1971) has recently summarized the status of geomagnetic models obtained from satellite surveys.

3. APPLICATION AND USE

In this section the five basic routines are briefly discussed, their operation is described, and the arguments of their transfer vectors are presented. A more detailed description of the three essential programs ALLMAG, GDALMG, and LINTRA is given in the Appendix, with an analysis of the methods employed and a review of the organization and structure of the codes. Program listings and sample outputs are given in the attachment.

A. ALLMAG

Subroutine ALLMAG is the most essential part of the entire program package: it calculates the spherical geocentric field vector components and the total field strength at any position defined in geocentric coordinates, when given a time, a model number, the geocentric distance to the position, and the values of four trigonometric functions derived from its geocentric latitude and longitude.

The variables in the calling sequence are

ALLMAG(MODEL, TM, RKM, ST, CT, SPH, CPH, BR, BT, BP, B)

The first seven arguments are input data:

MODEL : integer from 1 to 7 which chooses the field model (see Section 2);

TM : time for which the field coefficients are to be calculated, in decimal years A.D. (e.g., 1971.2);

RKM : geocentric distance to given position, in kilometers;

ALLMAG

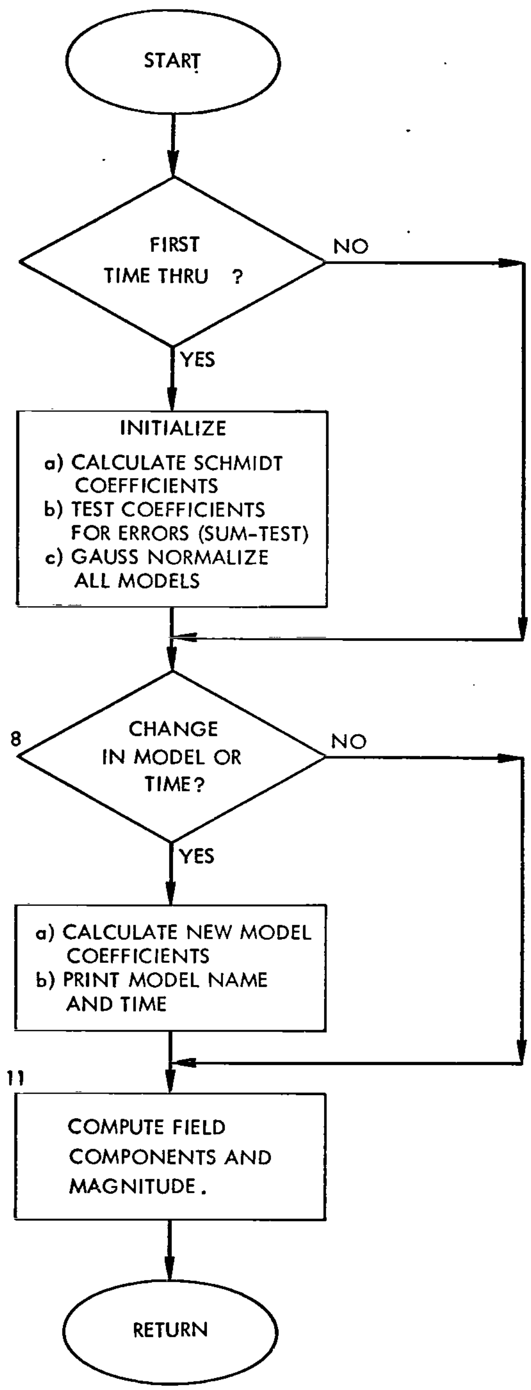

Figure 1. Flow Diagram of ALLMAG

ST, CT : sine and cosine functions of the geocentric colatitude θ (note: θ = 90 - latitude);

SPH, CPH : sine and cosine functions of the east longitude ϕ;

The last four arguments are output data:

BR, BT, BP : geocentric spherical field vector components (B_r, positive outward; B_θ, positive southward; and B_ϕ, positive eastward) at the given position, in gauss;

B : total magnetic field strength at the given position, in gauss.

All arguments except MODEL are floating point variables. There are no restrictions or limitations on the values of the input arguments other than on θ, which at the poles (θ = 0,180) results in a divide by zero, and MODEL, which must be an integer from 1 to 7.

For greatest efficiency, all calculations should be completed with one model and one time before changing either or both.

There are no READ or other input statements in ALLMAG. A PRINT statement is executed each time a new model or new date is inputted. In addition, a PRINT statement is executed if any of the coefficients fail the error test in the initialization process.

Figure 1 shows a flow diagram of the program. A complete listing of the short version is given in the attachment. The cards of each deck are appropriately labeled in columns 73-80 as ALMGSxxx (short version) or ALMGLxxx (long version) where the three last columns (xxx) contain the sequential numbering, which for the short version is incremented by 2 but for the long version by 1, in order to accommodate the 635 cards.

B. DEKMAG

Subroutine DEKMAG is designed as a substitute for ALLMAG in order to accommodate new geomagnetic field models as they become available. Instead of having coefficients built-in as DATA statements, it reads in coefficients for up to seven models as card input in standard format at execution time. Input decks corresponding to three of the ALLMAG models (IGRF, POGO 10/68, and POGO 8/69) are included in the package. The calling sequence is identical to ALLMAG, with each variable having the same meaning.

When DEKMAG is called as a subroutine for the first time, a READ sequence is initiated. A deck containing one parameter card plus from one to seven sets of coefficients are to be placed in the card input stream so as to be available when the subroutine is first called. The input stream is as follows:

Card 1:	NMODLS (Col. 5), NPRINT (Col. 10)
Deck A:	First model to be read in
Deck B:	Second model, etc.

The variable NMODLS, an integer from 1 to 7, controls the number of models to be read in. NPRINT controls the amount of information on each model printed in the output stream. If NPRINT = 0, only the label, as read in on the first card of the model deck, and the value of G(2,1), the largest coefficient, is printed out. If NPRINT = 1, the values of all coefficients are written on the output stream.

The decks containing the model coefficients should be in the standard format as distributed by the Cain group at GSFC. The format for each model deck is as follows (see also Cain et al., 1968):

First card:	Epoch (Cols. 4-9), Label (Cols. 10-73)
Intermediate cards:	N (Cols. 1-3), M (Cols. 4-6), GNM, HNM, GTNM, HTNM, GTTNM, HTTNM (11 Cols. each)
Last card:	Zero or blank in Cols. 1-3

The values of the parameters J and K, normally punched in Cols. 1 and 2, respectively, of the first card of the model decks distributed by the Cain group, are assumed by the program to be zero; thus the program assumes that the coefficients are for an oblate earth and are Schmidt-normalized. One should not, therefore, read in the Jensen and Cain coefficients (K = 1) or the Leaton, Malin, and Evans coefficients (J = 1) without modifying the program. Likewise, if DEKMAG is to be used with GDALMG, the branching statements in GDALMG for MODEL = 6 should be modified, unless the Leaton et al. model is to be read in as the sixth model.

The models are assigned a number corresponding to the order in which they appear in the input stream. The integer MODEL in the calling sequence then determines which model is to be used. A STOP command is encountered if MODEL < 1 or MODEL > NMODLS. Each time a new model or new time is selected, a statement is printed in the output stream with the model number,

label (taken from the first card of each model deck), and time selected. For greatest efficiency, all calculations with one model and one time should be completed before changing model or time.

DEKMAG is supplied in the short version (with subscripted variables and do loops) and single precision. A long version can be assembled by replacing cards DEKMG 200-270 with cards ALMGL 222-635. Instructions are given in the listings for converting to double precision.

C. ONEMAG

Subroutine ONEMAG is designed as a substitute for ALLMAG where, for simplicity, only one model is required. The coefficients for the IGRF 1965.0 model are built into the routine as DATA statements. There are no READ statements in the program. A model other than the IGRF can be substituted by selecting the appropriate DATA statements from ALLMAG and relabeling the coefficient matrices as LG and LGT.

The calling sequence is identical to ALLMAG except that the variable MODEL is removed. The routine is supplied as the short version, single precision.

D. GDALMG

Subroutine GDALMG represents a geodetic version of the magnetic field program. It actually is a short preparatory code that functions as an interface between a geodetic frame of reference and geocentric ALLMAG. Thus, it converts geodetic latitude and altitude above the geoid into geocentric colatitude and geocentric distance to the position and calculates the trigonometric functions for input into ALLMAG. The returning geocentric field vector components are transformed into geodetic components and the declination, inclination, and total horizontal field intensity are computed. The reference geoid is that adopted by the I.A.U. in 1964. A time and a model number have to be supplied to GDALMG for transmittal to ALLMAG.

The variables in the calling sequence of this routine are

```
GDALMG(MODEL, TM, GDLAT, GDLON, GDALT, X, Y, Z, F, H, DEC,AINC)
```

where the first five arguments are input data:

MODEL : same as in ALLMAG;

TM : same as in ALLMAG;

GDALMG

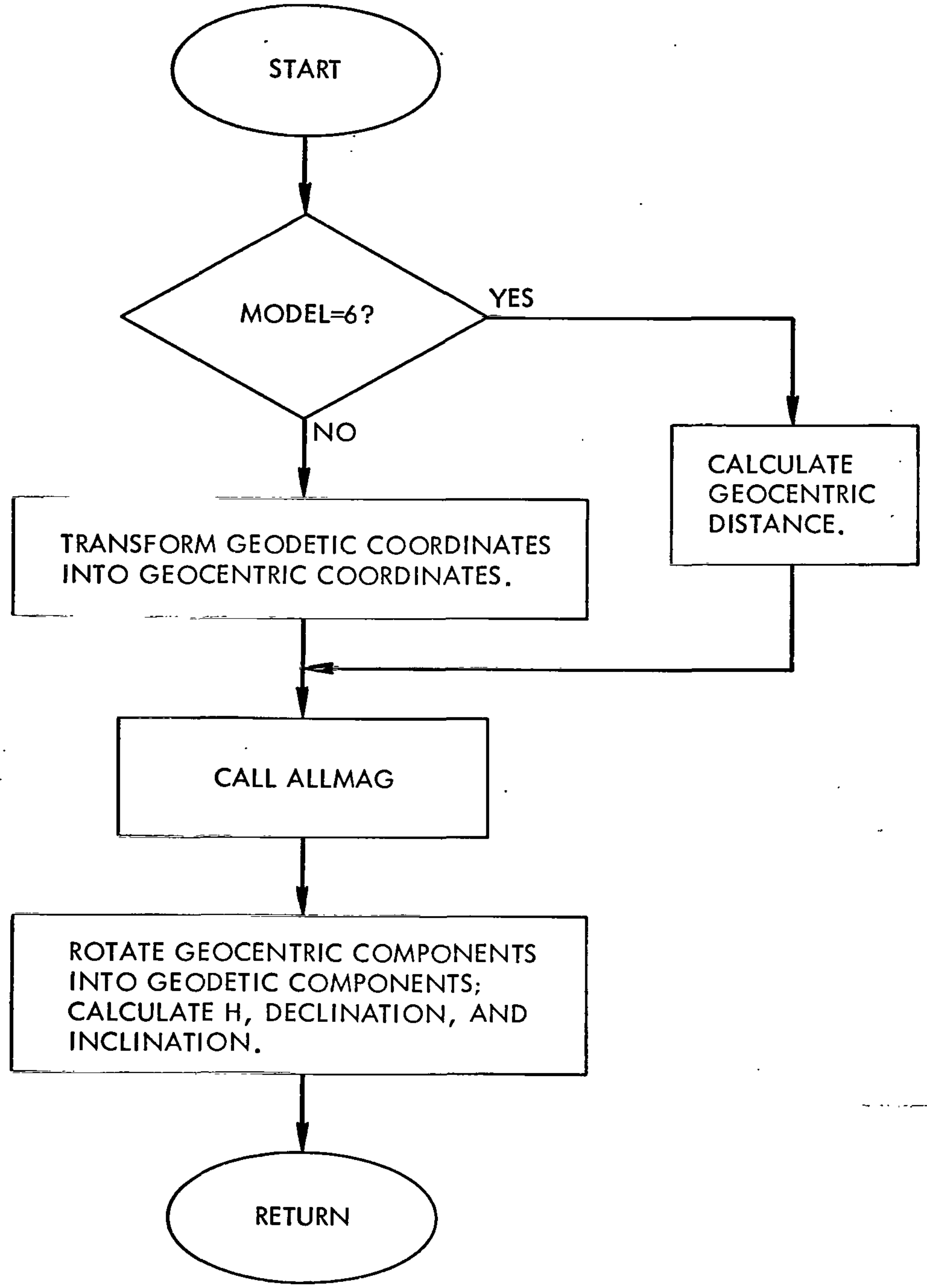

Figure 2. Flow Diagram of GDALMG

GDLAT : geodetic latitude, in degrees;

GDLON : east longitude, in degrees (invariant in the two coordinate systems);

GDALT : geodetic altitude or height above geoid, in kilometers.

The last seven arguments are output data:

X, Y, Z : geodetic north ($\approx$-B_θ), east (=B_ϕ), and downward vertical ($\approx$-B_r) field components at the given position, in gauss;

F : scalar magnitude or intensity of field at the given point, in gauss;

H : total horizontal field intensity, in gauss ($H^2 = X^2 + Y^2$);

DEC : declination, in degrees ($-180 < \text{DEC} < 180$), positive eastward;

AINC : inclination or dip angle, in degrees ($-90 < \text{AINC} < 90$), positive downward.

As in ALLMAG, all arguments except MODEL are floating point variables which have no restrictions on the values they may assume, except that GDLAT = ±90° will result in a divide by zero, and MODEL must be an integer from 1 to 7. As with ALLMAG, for greatest efficiency all calculations should be completed with one model and one time before changing either or both. There are no input-output statements in GDALMG. See ALLMAG section, however, for a description of its output statements.

A flow diagram of GDALMG is given in Figure 2 and a listing of the code is included in the attachment. The deck is labeled in Columns 73-80 as GDALMxxx, with the last three columns containing a sequential numbering of the cards by increments of 2.

E. LINTRA

The LINTRA code is an independent "Main" program that traces a field line passing through a given point on or above the geoid along either direction. In this process the program obtains intersects at any specified altitude level(s), it calculates and retains field strength and position of the minimum-B equator (if crossed), and it computes the arclength of the line-segment traversed. Designed around ALLMAG, the code accepts input coordinates for starting positions in either a geocentric or a geodetic system and it returns the coordinates for the

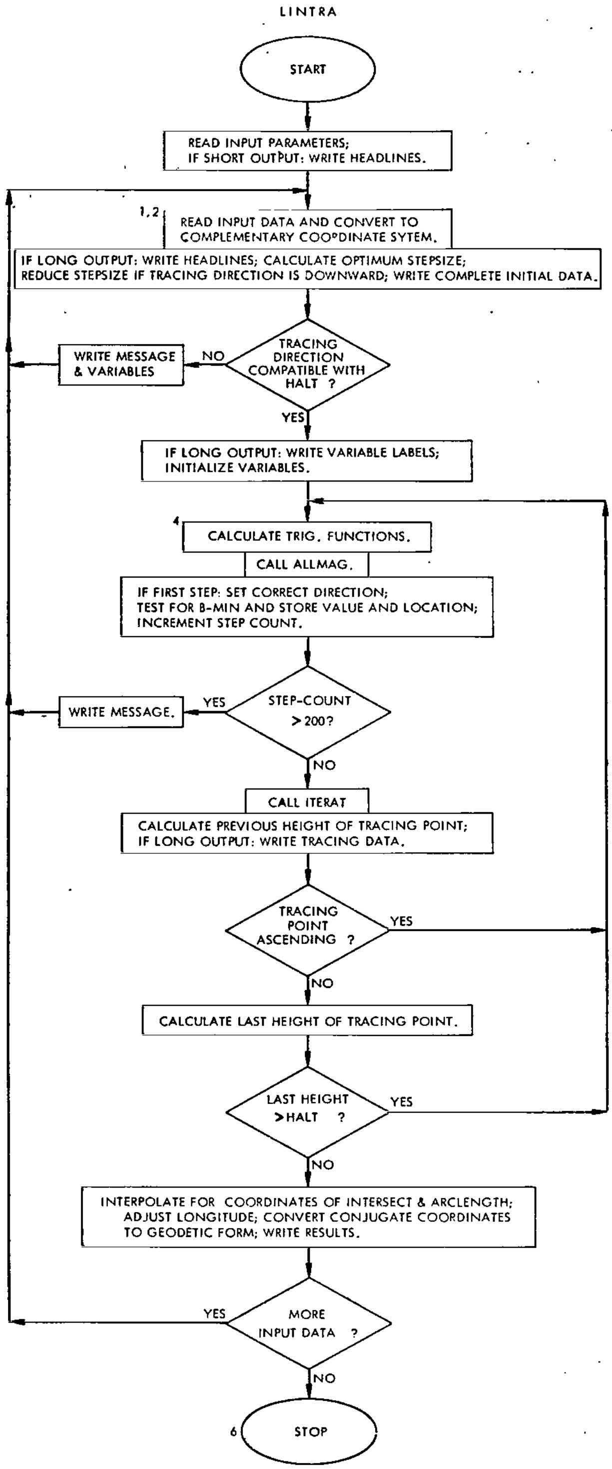

Figure 3. Flow Diagram of LINTRA

desired intersect in both systems. The tracing direction is input controlled; for a space point, this permits tracing the field line to the opposite hemisphere or down the same hemisphere, or both. The code requires a constant integration step size during execution time, but the increment may be changed from run to run. For maximum flexibility and efficiency the user has the option of an optimum step size calculated internally as a function of magnetic latitude and geocentric distance or of determining his own step size through input. In this case, lines 132 and 134 of the program should be commented out because in its present form, the code is designed to override the given input step size.

The code offers two output choices: either a continuous step by step account of the tracing process, where the coordinates of each successive point are printed with the positional total field strength and its components, plus the final results, or the final results only.

LINTRA has two supporting subroutines:

1. ITERAT, which performs the actual integration of the differential equations of the field line after a 7-step initialization process during which the tracing point is advanced by three increments, and

2. CONVRT, which performs all programmed conversions from geocentric to geodetic coordinates or vice versa.

The user-supplied input data for LINTRA are:

First input card (FORMAT(I5, F10.2, 2I5)):

MODEL : same as in ALLMAG;

TM : same as in ALLMAG;

NPRINT : output control:
= 1 : prints each integration step, plus final results;
≠ 1 : no running print-out, only final results;

ICOORD : reference system of input coordinates:
= 1 : geodetic;
= 2 : geocentric;

Each successive card (FORMAT(6F10.6, 2A4)):

If ICOORD = 1:

GDLAT, GLON, ALT : geodetic latitude and east longitude, in degrees, and altitude above geoid, in kilometers;

Or, if ICOORD = 2:

GCLAT, GLON, RKM : geocentric latitude and east longitude, in degrees, and geocentric distance, in kilometers;

DS : integration step size (tracing increment), in kilometers;

(Note: This parameter may be omitted, since the program determines DS unless cards LINTR 132 and 134 are commented out.)

DIR : tracing-direction control:
= >0. : traces towards higher altitudes;
= <0. : traces towards lower altitudes;

HALT : geodetic altitude of desired intersect, in kilometers;

LABEL1, LABEL2 : name of station or designation of origin (starting point).

MODEL, NPRINT, and ICOORD are integers; LABEL1 AND LABEL2 are alpha-numeric; all other arguments are floating-point variables. If DIR = -1.and HALT > ALT, the line is not traced.

If long output has been specified (NPRINT = 1), the code will print the following variables for every integration step:

L : current step-count;

DLATP, DLONP : geocentric latitude and longitude of last position (L-1), before iteration, in degrees;

RP, HP : geocentric distance and altitude of last position (L-1), before iteration, in kilometers;

BR, BT, BP : same as in ALLMAG, at last position (L-1);

B : same as in ALLMAG, at last position (L-1).

Line-tracing proceeds until either (a) the number of steps exceeds 200 or (b) the intersect is reached on the downward path (i.e., for R $<$ RP because the tracing skips over the intersect in the same hemisphere, where R $>$ RP). If a HALT $>$ initial ALT in the same hemisphere is desired, card LINTR200 should be removed or commented out.

When the specified intersect has been reached, the final results are printed:

PLAT, PLON, PRKM	:	geocentric coordinates of intersect, in degrees and kilometers;
PGDLAT, PLON, PGALT	:	geodetic coordinates of intersect, in degrees and kilometers above the geoid;
ARC	:	length of traced field line segment, in kilometers.

A flow diagram of LINTRA is given in Figure 3 and a listing of the program is contained in the attachments.

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We are indebted to Joseph Cain, Robert Langel, and Ronald Sweeney for discussions of the characteristics of various models and for the use of their routines FIELD and FIELDG, in both the long and short versions, which served as the basic framework for ALLMAG. We thank Eugene Fabiano and Louis Hurwitz of the Coast and Geodetic Survey for their deck to compute the USC&GS Field and for their testing of ALLMAG on a CDC 6600.

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APPENDIX A

COMMENTS ON ALLMAG

ALLMAG is the fundamental routine which calculates the three components of the vector field from a spherical harmonic expansion. The relevant mathematical formulation is readily available in, for example, Chapman and Bartels (1940) and Cain et al. (1968), and we shall not repeat it here. We have adhered to Cain's treatment in most respects. ALLMAG is essentially similar in its basic mathematics to Cain's subroutine FIELD, with the following differences in the organization of the program:

1. Any one of seven models may be selected; successive selection of different models is possible.

2. All coefficients for the seven models are built into ALLMAG as DATA statements. ALLMAG contains no READ statements.

3. An internal sum-test is performed on all the coefficients to check for accuracy the first time the subroutine is called, and all coefficients are then converted from Schmidt to Gauss normalization.

4. Different time periods may be selected if desired.

5. A statement indicating the model and time period selected is written on the output stream the first time ALLMAG is called, and each successive time that either MODEL or TM is changed.

6. ALLMAG is completely self-contained if input and output in geocentric coordinates is desired. No other supporting routines are needed. (GDALMG should be used with ALLMAG if geodetic input and output is desired.)

All coefficients are stored in the DATA statements in their Schmidt-normalized form, since this is the normalization used in all recently-published models (i.e., in Cain's notation, K = 0 for all models). All models except Model 6 (Leaton et al., 1965) were derived using an oblate earth (J = 0 in Cain's notation). ALLMAG assumes that the appropriate conversion of input quantities into geocentric coordinates has already been performed. See the appendix section on GDALMG for a discussion of these conversions.

The variable TM used as input to ALLMAG may specify a time that is earlier or later than the epoch assigned to each model; the time derivatives or secular-variation terms are then used to update or predate the coefficients. However, it is best not to input a time more than a few years away from the data range of a given model, i.e., the actual time period during which geomagnetic data were used to define the model. See Section 2 on models for further discussion of this point.

ALLMAG is designed to handle any sets of coefficients with up to 168 terms, that is, n_{max} = 12 (Fortran NMAX = 13), but the "short version" can be easily modified to accept models with a larger n_{max}.

The coefficients in the data statements have been checked very carefully against the published coefficients for each model, and we believe that there are no errors. To further reduce the possibility of errors due to misplaced data cards, that is, to insure that the data cards with the coefficients are in proper sequence, a special test was included in the code, which during initialization compares the sum of the products of the model-coefficients times their sequence number with precalculated values placed into a data statement under the variable name LSUM. This test is performed only once for all models during the first call, in the initialization step. If a discrepancy is detected, a message will be printed, indicating which model is being questioned and giving the precalculated as well as the computed sums; the run is then terminated.

Comment statements throughout ALLMAG highlight significant parts or functions of the routine while all input/output variables, constants, and parameters are defined and identified in comment statements at the beginning of each routine.

ALLMAG was tested and has successfully run on IBM-360 computers (models 40, 75, and 91) in the 029 key-punch version (EBCDIC). It was also tested with equal success on an IBM-7094, a CDC-6600, and a UNIVAC-1108 computer in the 026 key-punch version (BCD). To run the program on the GSFC IBM-7094 we had to trim the code by three models to decrease its size because of limitations in the system's capabilities with regards to table-space.

Timing of the long version of ALLMAG on the IBM 360/91 produced the following results:

Model	Average Time Per Call
IGRF (n_{max} = 8)	340 microsecs
GSFC 12/66 (n_{max} = 10)	450 microsecs

These times are averages, obtained from five separate runs of one thousand B calculations each. They include the time used for initialization, coefficient recalculation, and I/O interrupt (but not actual I/O time). The short version times are about a millisecond per call.

The model coefficients are stored as integers rather than real variables. This has two advantages: we found that compilation time is significantly less, and the sum-test, using integer arithmetic, can be exact. The integers are converted to real variables and divided by the appropriate power of 10 (stored as G1 (1,1), etc.) at the same time as they are converted from Schmidt to Gauss normalization. Equivalence statements are used to conserve storage space.

The EBCDIC short version is supplied in single precision and the EBCDIC long version is supplied in double precision. Only two card changes are necessary to convert either version from single to double precision or vice versa; these changes are indicated in the comment cards. The BCD decks are supplied in single precision only.

APPENDIX B

COMMENTS ON GDALMG

The subroutine GDALMG accepts input in geodetic coordinates, i.e., geodetic latitude and altitude above the geoid. It converts these quantities into geocentric co-latitude and geocentric distance for input into ALLMAG. (Geodetic and geocentric longitude are equivalent.) The geocentric field components obtained from ALLMAG are then converted into geodetic components, and the horizontal component, declination, and inclination are calculated.

The geometry is shown in Figure 4, where the earth is depicted as a grossly exaggerated ellipsoid. The altitude $\underline{h}$ is measured along a plumb line perpendicular to the geoid; and the geodetic latitude $\underline{\lambda}$ is measured at the intersection of the plumb line with the equatorial plane.

The reference geoid is that adopted by the International Astronomical Union in 1964. The two parameters defining this geoid are

$$a = 6378.16 \text{ km}$$

$$f = \frac{a - b}{a} = \frac{1}{298.25}$$

where $\underline{a}$ is the equatorial radius, $\underline{b}$ is the polar radius, and $\underline{f}$ is the flattening factor. From these parameters we can derive the following quantities:

$$b = 6356.7747 \text{ km}$$

$$a^2/b^2 = 1/(1 - f)^2 = 1.00673966$$

$$e^2 = a^2/b^2 - 1 = 0.00673966$$

where $\underline{e}$ is the so-called second eccentricity. The geocentric latitude at the surface of the geoid β is related to the geodetic latitude by

$$\tan \beta = \frac{b^2}{a^2} \tan \lambda$$

from which

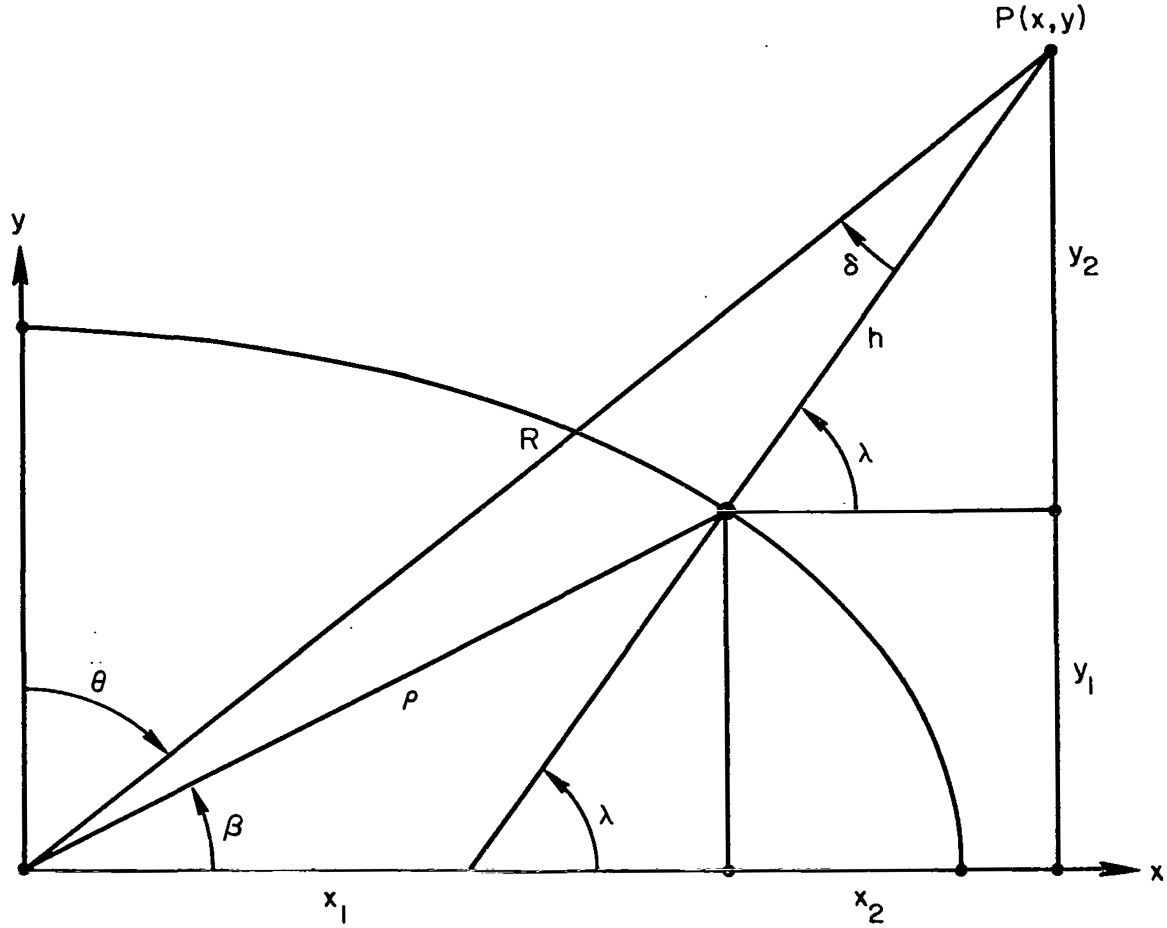

Figure 4. Trigonometric Relationships between Geocentric and Geodetic Coordinate Systems.

$$\sin \beta = \sin \lambda \Bigg/ \left(\sin^2 \lambda + \frac{a^4}{b^4} \cos^2 \lambda\right)^{1/2}$$

The geocentric distance to the geoid, ρ, is given by

$$\rho = a/(1 + e^2 \sin^2 \beta)^{1/2}$$

The coordinates (x,y) of the space point P are then given by

$$x = \rho \cos \beta + h \cos \lambda$$

$$y = \rho \sin \beta + h \sin \lambda$$

and thus the geocentric distance R and colatitude θ are

$$R = (x^2 + y^2)^{1/2}$$

$$\theta = \cos^{-1}(y/R)$$

The small angle δ at the space point between the downward vertical and the geocentric direction is given by

$$\delta = \theta + \lambda - 90°$$

which is positive for positive latitudes and negative for negative latitudes. Thus

$$\sin \delta = \sin \theta \sin \lambda - \cos \theta \cos \lambda$$

$$\cos \delta = \cos \theta \sin \lambda + \sin \theta \cos \lambda$$

All of the above equations are exact for any altitude and an ellipsoid of any eccentricity.

The geodetic field components X (northward), Y (eastward), and Z (downward vertical) are related to the geocentric components B_r, B_θ, and B_ϕ approximately by

$$X \approx -B_\theta$$

$$Y = B_\phi$$

$$Z \approx -B_r$$

but to get the exact relationship we must rotate B_r and B_θ through the small angle $\underline{\delta}$:

$$X = -B_\theta \cos \delta - B_r \sin \delta$$

$$Z = B_\theta \sin \delta - B_r \cos \delta$$

Finally, the horizontal component $\underline{H}$, declination $\underline{D}$, and inclination $\underline{I}$ are defined by

$$H = (X^2 + Y^2)^{1/2}$$

$$\sin D = Y/H$$

$$\cos D = X/H$$

$$\tan I = Z/H$$

Model number 6 (Leaton et al., 1965) was derived from surface measurements without correcting for the oblateness of the earth (i.e., in Cain's notation, J = 1 for this model). Therefore, to use this model properly, altitudes should be referenced to a sphere of radius 6371.2 km instead of the geoid. For this model GDALMG sets the geocentric latitude equal to the geodetic latitude and sets $\underline{R} = 6371.2 + \underline{h}$.

Although our equations are somewhat simpler, the geodetic transformations outlined here are exactly equivalent to those given by Cain et al. (1968) in describing the corresponding portions of FIELDG. (Note, however, that the expression for FAC at the bottom of their page 5 should be squared; it is correct in FIELDG.) Identical results are obtained from GDALMG and FIELDG if the same model and time period are used.

APPENDIX C

COMMENTS ON LINTRA

Field-line tracing routines are useful in a number of applications: for example, in locating the position of conjugate points, in determining mirror point locations for particles at a given position with a given pitch angle, in calculating the value of the second adiabatic invariant prior to calculating the McIlwain L-parameter, in ascertaining the topology of the magnetosphere, etc. Conceptually, the process is straightforward: given a point in space and a magnetic field model, we wish to trace a line passing through that point which is everywhere parallel to the local field direction as determined by the model. The brute-force technique is to approximate the line by a series of short, straight line segments; each segment is parallel to the local field direction only at one end. Then at the other end of the segment, another straight line segment is constructed parallel to the field at that point. The true curve is approximated by making the segments as short as is required to achieve the desired accuracy. Such a technique is usually time-consuming because of the necessity of keeping each segment short in order to approximate the true curve.

A much more satisfactory approach is to solve the differential equations defining a field line. In cartesian coordinates these are

$$dx/ds = B_x/B$$

$$dy/ds = B_y/B$$

$$dz/ds = B_z/B$$

where ds is the infinitesimal arc length along the line.

In spherical coordinates these equations become

$$dr/ds = B_r/B$$

$$d\theta/ds = (1/r)\,(B_\theta/B)$$

$$d\phi/ds = (1/r \sin\theta)\,(B_\phi/B)$$

The LINTRA line-tracing routine integrates these equations with the aid of subroutine ITERAT, using an Adams 4-point integration formula. Since each

integration step takes into account the local curvature of the line, a much larger step size can be used without sacrificing accuracy.

An early version of this routine was used by one of us to calculate conjugate-point positions (Roederer et al., 1965). This program was later documented in a modified form as LINTRA (Stassinopoulos, 1968). It should be noted that our technique differs in principle from that used in the LINES subroutine of McIlwain's INVAR program to calculate B-L coordinates. LINES varies the step size along the field line as its curvature changes; LINTRA, on the other hand, uses a constant, predetermined step size.

The present LINTRA is essentially an improved and faster version of the old code, adapted to use the new ALLMAG and to which some desirable features were added, as for example the coordinate conversion facility, the output choice, the internal functional determination of optimum integration step size and others. Retained in the program was the search for and the storage of the minimum-B location encountered in the integration process; the respective geocentric coordinates are easily accessible for output in cards LINTR 174-178. It should be noted, however, that the saved minimum-B value may not correspond to the true minimum-B equator. In fact, the minimum-B equator may not lie at all between the origin and the conjugate intersect. In that case the stored minimum-B location will lie very close to either one of these two end-points of the field line. If crossed in the tracing process, the location of the minimum-B equator is approximated along the field line with a maximum error of plus or minus one arc increment.

An addition to the new LINTRA is the calculation of an optimum step size DS as an empirical function of the geomagnetic dipole coordinates of the starting point:

$$\mathrm{DS} = .06\ R/\cos^2 \lambda_d - 370\ \mathrm{km}$$

where $\underline{R}$ is the geocentric distance in kilometers and $\underline{\lambda_d}$ is the dipole latitude, defined by

$$\sin \lambda_d = \cos 11.5^\circ \sin \lambda_g + \sin 11.5^\circ \cos \lambda_g \cos (\phi_g + 69^\circ)$$

where $\underline{\lambda_g}$ and $\underline{\phi_g}$ are the geocentric latitude and east longitude, and where the geocentric position of the north dipole is assumed to be at 11.5° colatitude, 69° west longitude. Since the empirical formula gives very large values near the magnetic poles, the step size is limited to a maximum of 3000 kms. We have found that the step size given by this formula is large enough to trace to

the opposite hemisphere in less than 200 steps, yet small enough to insure high accuracy. We have found that if high accuracy is not required, DS can be multiplied by factors of 2 to 5, thus saving significant amounts of computer time. If desired, the user can input the step size, removing or commenting out cards LINTR 130-134.

If one wishes to trace a line initially towards the earth's surface (DIR < 0), a shorter step size is usually desirable. In this case the empirical formula is modified so that DS is no greater than (ALT-HALT)/20, where ALT is the initial altitude and HALT is the final desired altitude.

The old concept of a user-controlled tracing direction has not been changed. However, the range of applicability of new LINTRA was expanded so as to include intersects in the opposite hemisphere which were formerly excluded, namely intersects that have a higher altitude than that of the origin.

In its present form, the program bypasses an intersect in the same hemisphere that lies above the initial point (HALT > ALT). But this bypass can be removed by commenting out card LINTR 200 from the deck. If the bypass is removed, and if the desired intersect lies close to the initial point, especially when large L-values are involved (high latitudes), it is necessary to override the internally calculated step size and input a step size small enough for effective tracing, that is, no larger than $0.1 \times$ (HALT-ALT).

Tracing is terminated whenever the altitude of the point on the field line becomes equal to or less than HALT (the specified altitude for the intersect). When this point is reached, the latitude and longitude at the conjugate intersect altitude h_i (=HALT) are determined by a quadratic interpolation formula. If λ_1, λ_2, and λ_3 are successive values of the latitude at altitudes h_1, h_2, and h_3, which bracket the desired intersect altitude h_i, then the latitude at h_i is given by

$$\lambda_i = \frac{(h_2-h_3)(h_i-h_2)(h_i-h_3)\lambda_1 + (h_3-h_1)(h_i-h_3)(h_i-h_1)\lambda_2 + (h_1-h_2)(h_i-h_1)(h_i-h_2)\lambda_3}{(h_1-h_2)(h_1-h_3)(h_2-h_3)}$$

The interpolated longitude is given by a similar formula.

Finally, in regard to use and results it should be noted that:

1. Tracing accuracy improves only slightly with decreasing integration step size while running-time increases disproportionally; therefore, the calculated step sizes are a good compromise.

2. The location of conjugate points or intersects will vary with every field model; the dispersion with different models may be substantial; a "true" position, in an absolute sense, cannot be established. More accurate results can be obtained:

   a. For low L-values ($L < 3$), by using that model whose components differ the least from actual surface measurements, over adjacent areas of the globe;

   b. For high L-values ($3 < L < 6$), by the inclusion of external source terms into the model representation so as to account for contributions resulting from the ring current in the magnetosphere and the currents on the magnetospheric boundary, which contributions become significant at L-values greater than 4;

   c. By considering and accounting for:

      (1) diurnal effects (local time effects)

      (2) severe magnetic storm effects

      (3) seasonal effects

      (4) solar cycle effects

3. The indiscriminate application of the time derivatives of a field model to predict the expected secular variations too far in the future may introduce a larger error into the calculations than expected (see Section 2).

Subroutine ITERAT is a slightly modified version of the old DPNV program (Stassinopoulos, 1968). It uses a bootstrap method of getting started along the field line; three steps of length DS are taken in the first seven iterations. The subroutine stores the derivatives of the spatial quantities from the preceding steps, and henceforth one step along the curved field line is taken each time ITERAT is called.

The subroutine CONVRT is used to transform coordinates from geocentric to geodetic or vice versa. The geodetic to geocentric conversion is identical to the one used in GDALMG. The geocentric to geodetic conversion uses the formulas given by Morrison and Pines (1961). The two parts are compatible, i.e., a geodetic to geocentric to geodetic conversion returns the same initial values with six-figure accuracy.

APPENDIX D

USE OF ALLMAG WITH INVAR

For the benefit of the numerous users of McIlwain's INVAR program, which calculates the magnetic parameter L, we have replaced subroutine NEWMAG (corresponding to the old MAGNET) with ALLMAG and named the modified deck "INVARA" (for INVAR-ALLMAG). Although very minor changes were made in three subroutines only, the letter A was added to the end of the name of all programs in the deck to differentiate it from the standard versions. The routines INVAR, START, and LINES were modified. Their input-output arguments were implemented to carry the input parameters "MODEL" and "TM" needed by ALLMAG, while statements number 28-36 and 64-74 were added to START and statements 112-122 to LINES, in order to produce the appropriate calling sequence for ALLMAG. Finally, a main program was constructed to read sample input points in either geocentric or geodetic coordinates, convert to the opposite coordinate system, call INVARA, and print results. The subroutine CONVRT (see LINTRA appendix) was added to the package to perform the conversions required by the main program.

```
      SUBROUTINE ALLMAG(MODEL,TM,RKM,ST,CT,SPH,CPH,BR,BT,BP,B)            ALMGS002
C ****  GEOCENTRIC VERSION OF GEOMAGNETIC FIELD ROUTINE                   ALMGS004
C ****  SINGLE PRECISION DECK FOR IBM 360 MACHINES (EBCDIC, 029 PUNCH)   ALMGS006
C ****  SHORT DECK, USES SUBSCRIPTED VARIABLES AND DO LOOPS              ALMGS008
C ****  EXECUTION TIME PER CALL 3 TIMES GREATER THAN LONG DECK           ALMGS010
C ****  PROGRAM DESIGNED AND TESTED BY E G STASSINOPOULOS AND G D MEAD,  ALMGS012
C ****  CODE 641, NASA GODDARD SPACE FLT CTR, GREENBELT, MD 20771        ALMGS014
C  *****  INPUT: MODEL    CHOICE OF 7 MODELS - SEE BELOW                 ALMGS016
C  *****         RKM      GEOCENTRIC DISTANCE IN KILOMETERS              ALMGS018
C  *****         TM       TIME IN YEARS FOR DESIRED FIELD                ALMGS020
C  *****         ST,CT    SIN & COS OF GEOCENTRIC COLATITUDE             ALMGS022
C  *****         SPH,CPH  SIN & COS OF EAST LONGITUDE                    ALMGS024
C  ***** OUTPUT: BR,BT,BP GEOCENTRIC FIELD COMPONENTS IN GAUSS           ALMGS026
C  *****         B        FIELD MAGNITUDE IN GAUSS                       ALMGS028
C  *****  NOTE: FOR GREATEST EFFICIENCY, COMPLETE ALL CALCULATIONS WITH  ALMGS030
C               ONE MODEL AND ONE TIME BEFORE CHANGING MODELS OR TIME.   ALMGS032
C  *****  FOR DOUBLE PRECISION ADD THE FOLLOWING CARD                    ALMGS034
C     IMPLICIT REAL*8(A-H,O-Z)                                           ALMGS036
C  *****  SEE END OF DECK FOR ONE MORE CHANGE                            ALMGS038
      REAL*8 LABEL(4,7) /  'HENDRICKS&CAIN 99-TERM GSFC 9/65 CAIN ET.AL.ALMGS040
     A 120-TERM GSFC 12/66 CAIN&LANGEL 143-TERM POGO 10/68 CAIN&SWEENEY ALMGS042
     B120-TERM POGO 8/69    IGRF 1965.0 80-TERM 10/68    LEATON MALIN EVALMGS044
     CANS 80-TERM 1965   HURWITZ US C&GS 168-TERM 1970'/                 ALMGS046
      DIMENSION TO(7),NMX(7),ISUM(7,3),G(13,13)                          ALMGS048
      DATA TO/4*1960.,2*1965.,1970./,NMX/10,11,12,11,9,9,13/             ALMGS050
      INTEGER LSUM(7,3)/-1646106,-1795169,-1865298,-1777057,-158472,     ALMGS052
     A-156856,-2191704,-62661,-96778,-181519,-83555,-9569,-9599,         ALMGS054
     B-8593,1,-10618,5*1/                                                ALMGS056
      INTEGER*4 G1(13,13),GT1(13,13),GTT1(13,13),G2(13,13),GT2(13,13),   ALMGS058
     1 GTT2(13,13),G3(13,13),GT3(13,13),GTT3(13,13),G4(13,13),           ALMGS060
     2 GT4(13,13),GTT4(13,13),G5(13,13),GT5(13,13),GTT5(13,13),          ALMGS062
     3 G6(13,13),GT6(13,13),GTT6(13,13),G7(13,13),GT7(13,13),GTT7(13,13)ALMGS064
     4 ,LG(13,13,7),LGT(13,13,7),LGTT(13,13,7)                           ALMGS066
      REAL*4     GG(13,13,7),GGT(13,13,7),GGTT(13,13,7),SHMIT(13,13)     ALMGS068
      EQUIVALENCE (G1(1),GG(1),LG(1)), (GT1(1),GGT(1),LGT(1)),           ALMGS070
     A      (GTT1(1),GGTT(1),LGTT(1)),                                   ALMGS072
     B (G2(1),LG(1,1,2)), (GT2(1),LGT(1,1,2)), (GTT2(1),LGTT(1,1,2)),    ALMGS074
     C (G3(1),LG(1,1,3)), (GT3(1),LGT(1,1,3)), (GTT3(1),LGTT(1,1,3)),    ALMGS076
     D (G4(1),LG(1,1,4)), (GT4(1),LGT(1,1,4)), (GTT4(1),LGTT(1,1,4)),    ALMGS078
     E (G5(1),LG(1,1,5)), (GT5(1),LGT(1,1,5)), (GTT5(1),LGTT(1,1,5)),    ALMGS080
     F (G6(1),LG(1,1,6)), (GT6(1),LGT(1,1,6)), (GTT6(1),LGTT(1,1,6)),    ALMGS082
     G (G7(1),LG(1,1,7)), (GT7(1),LGT(1,1,7)), (GTT7(1),LGTT(1,1,7))     ALMGS084
C  ***** THE FOLLOWING DATA CARDS CONTAIN THE FIELD COEFFICIENTS         ALMGS086
C  ***** FOR THE FOLLOWING SEVEN MODELS:                                 ALMGS088
C  *****  G1,GT1: HENDRICKS & CAIN      99-TERM  GSFC  9/65  EPOCH 1960.ALMGS090
C  *****  G2,GT2,GTT2: CAIN ET. AL.    120-TERM  GSFC 12/66  EPOCH 1960.ALMGS092
C  *****  G3,GT3: CAIN & LANGEL        143-TERM  POGO 10/68  EPOCH 1960.ALMGS094
C  *****  G4,GT4: CAIN & SWEENEY       120-TERM  POGO  8/69  EPOCH 1960.ALMGS096
C  *****  G5,GT5: IGRF 1965.0           80-TERM       10/68  EPOCH 1965.ALMGS098
C  *****  G6,GT6: LEATON MALIN & EVANS 1965         80-TERM  EPOCH 1965.ALMGS100
C  *****          FOR MODEL 6 (LME 1965) SET RKM = 6371.2 + ALTITUDE     ALMGS102
C  *****  G7,GT7: HURWITZ US COAST & GEODETIC S.  168-TERM  EPOCH 1970.ALMGS104
      DATA G1 / 10, -304249,-15361,13009,9576,-2277,498,709,48,99,3*0,   ALMGS106
     A 57748,-21616,30002,-19870,8028,3595,607,-572,67,29,3*0,-19498,    ALMGS108
     B 2043,15853,12904,5026,2313,45,56,-88,74,3*0,-4310,2308,-1300,8712ALMGS110
     C ,-3940,-312,-2417,75,-138,-156,3*0,1520,-2684,29,-2505,2714,      ALMGS112
     D -1573,-12,-244,-33,114,3*0,86,1212,-1160,-1104,799,-652,5,-15,71,ALMGS114
     E 111,3*0,-119,1028,609,-272,-124,-116,-1091,141,-56,10,3*0,-540,   ALMGS116
     F -244,-91,22,276,-211,-201,58,117,4*0,69,-122,58,-170,26,236,-25,  ALMGS118
     G -160,64,16,3*0,-220,156,51,-35,-18,96,121,2,-25,15,42*0 /         ALMGS120
```

```
 DATA GT1 / 100, 2059,-2907,266,-86,255,-70,6*0,-394,602,121,-1003,ALMGS122
H 194,-8,99,6*0,-1369,-1578,-70,163,-117,153,85,6*0,649,293,-924,  ALMGS124
I -130,-54,-42,211,6*0,-177,-154,318,-548,-417,-72,157,6*0,304,288,ALMGS126
J -186,125,80,164,-9,6*0,-139,12,153,-73,-6,45,6,84*0/             ALMGS128
 DATA GTT1 /1,168*0/                                                ALMGS130
 DATA G2 / 10, -304012,-15401,13071,9493,-2335,492,722,85,104,-29, ALMGS132
A 2*0,57782,-21638,29979,-19889,8035,3557,575,-537,65,58,-9,        ALMGS134
B 2*0,-19320,2029,15903,12768,5029,2284,-8,79,-93,75,-22,2*0,-4254,ALMGS136
C 2278,-1338,8812,-3977,-288,-2383,156,-96,-151,8,2*0,1603,-2743,  ALMGS138
D 23,-2466,2665,-1579,-15,-243,-61,121,-28,2*0,51,1178,-1148,-1089,ALMGS140
E 824,-622,-20,-36,55,47,64,2*0,-121,1044,566,-234,-148,-133,-1089,ALMGS142
F 155,-81,2,47,2*0,-537,-274,-81,70,243,-225,-214,36,130,16,-2,2*0,ALMGS144
G 54,-117,42,-153,46,219,-7,-171,74,9,18,2*0,-224,138,63,-30,-19,  ALMGS146
H 90,115,1,-15,2,20,2*0,-1,45,-10,26,-44,-13,-36,40,10,-20,11,28*0/ALMGS148
 DATA GT2 / 100, 1403,-2329,-93,145,161,-42,-57,35,-10,-1,2*0,-371,ALMGS150
I 876,-9,-1062,90,60,82,-34,50,-13,-13,2*0,-1431,-1662,-456,231,   ALMGS152
J -175,334,82,-144,170,-120,88,2*0,520,253,-698,-589,66,-4,235,-90,ALMGS154
K -11,8,-18,2*0,-219,-14,188,-652,-301,-60,83,3,34,-8,17,2*0,224,  ALMGS156
L 159,-261,50,-12,176,1,-60,-7,-39,-2,2*0,5,9,255,-119,33,84,23,-17ALMGS158
M ,43,-36,5,2*0,-96,1,43,75,-33,49,90,-64,-15,47,17,2*0,-50,-21,3, ALMGS160
N -79,5,10,-36,-43,-42,37,16,2*0,66,54,3,35,-3,-1,45,-5,75,-46,31, ALMGS162
O 2*0,-61,-64,2,5,-63,-7,7,-3,-2,-45,-23,28*0/                      ALMGS164
 DATA GTT2 /1000,-62,-154,-123,1,45,-6,-14,6,-5,-3,2*0,-43,114,-18,ALMGS166
P-27,-44,1,15,-6,8,-1,-3,2*0,54,-16,-253,28,17,75,10,-34,39,-27,20,ALMGS168
Q 2*0,95,-7,79,-183,7,8,50,-4,-8,5,-8,2*0,4,56,-35,-47,-97,15,-11, ALMGS170
R -6,15,-7,7,2*0,-46,7,-7,1,-24,56,26,-27,-2,-6,1,2*0,20,-11,15,   ALMGS172
S -29,29,-10,23,-1,5,-9,1,2*0,-14,16,14,5,-8,16,11,-4,-8,6,1,2*0,  ALMGS174
T -15,-12,5,-11,0,-3,-9,-3,-7,5,5,2*0,22,7,-2,9,6,-1,9,-4,19,-9,4, ALMGS176
U 2*0,-12,-14,1,1,-11,-1,1,-1,1,-6,-2,28*0/                         ALMGS178
 DATA G3 / 10, -304650,-15414,13258,9591,-2343,491,759,74,110,-26, ALMGS180
A 23,0,57910,-21633,29763,-19837,8196,3577,545,-524,60,66,-20,-18, ALMGS182
B 0,-19772,1566,16075,13169,4864,2339,48,80,-81,18,10,-21,0,-4453, ALMGS184
C 2334,-949,8420,-3724,-210,-2491,100,-92,-125,-55,55,0,1354,-2667,ALMGS186
D 207,-2415,2562,-1471,17,-367,-8,158,-7,-15,0,169,1133,-1287,-1151ALMGS188
E ,1303,-452,-37,-83,91,17,75,24,0,-96,1064,568,-272,-149,-43,-916,ALMGS190
F 66,-114,26,78,-35,0,-579,-250,-8,63,95,-117,-376,-227,79,87,17,  ALMGS192
G -13,0,101,-130,115,-164,55,223,-49,-262,351,51,-53,25,0,-204,144,ALMGS194
H 6,-15,14,34,148,24,-9,-24,13,-12,0,11,9,-3,75,-23,14,-5,43,80,   ALMGS196
I -137,-27,127,0,-8,44,-1,-39,-6,18,-32,8,-59,-17,105,50,14*0/     ALMGS198
 DATA GT3 / 100,2542,-2390,-559,-62,272,-61,-89,61,-24,-1,3,0,-466,ALMGS200
J 988,350,-1152,-251,48,106,-21,-12,30,-9,11,0,-707,-1070,-214,-441ALMGS202
K ,-122,317,62,-108,87,4,12,5,0,848,68,-1489,287,-296,-246,396,70, ALMGS204
L -33,4,19,-30,0,345,-39,-87,-652,86,-89,-94,107,-14,-40,-20,1,0,5,ALMGS206
M 300,32,311,-635,-315,149,96,-85,-28,-2,-34,0,-26,-48,258,-80,50, ALMGS208
N 82,-167,101,99,-57,-43,48,0,-87,-46,-102,25,188,-243,232,523,81, ALMGS210
O -132,-33,52,0,-15,-10,-122,-26,15,-37,29,91,-498,-14,103,-19,0,  ALMGS212
P -38,16,67,-14,-83,130,-33,-38,99,50,22,-3,0,21,5,54,-26,-30,-3,  ALMGS214
Q -39,-2,-104,79,46,-165,0,35,-26,-17,17,18,-50,23,-34,37,22,-155, ALMGS216
R -40,14*0/                                                         ALMGS218
 DATA GTT3 /1,168*0/                                                ALMGS220
 DATA G4 / 10,-304708,-15425,13334,9647,-2375,448,793,99,96,-17,    ALMGS222
A 2*0,57571,-21702,29893,-19826,8108,3566,594,-516,32,93,-22,2*0,  ALMGS224
B -19793,2661,15559,12922,5068,2498,-37,-3,-56,31,13,2*0,-4249,     ALMGS226
C 2417,-1740,8336,-3978,-143,-2324,89,-165,-120,16,2*0,1344,-3037, ALMGS228
D 194,-2764,2247,-1497,96,-335,-33,153,-22,2*0,51,1080,-1073,-1083,ALMGS230
E 1171,-757,20,-33,50,7,94,2*0,-76,1181,583,-181,-270,1,-831,100,  ALMGS232
F -120,8,87,2*0,-544,-212,-87,55,151,-236,-278,39,102,4,3,2*0,98,  ALMGS234
G -162,99,-189,106,206,-2,-207,187,62,-24,2*0,-254,128,31,-25,-21, ALMGS236
H 73,127,47,7,-38,-1,2*0,29,35,-7,66,-50,10,-28,21,42,-88,53,28*0/ ALMGS238
 DATA GT4 / 100,2682,-2366,-724,-157,359,12,-160,19,17,-3,2*0,225, ALMGS240
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     I 1003,150,-1142,-118,58,38,-26,27,-8,-8,2*0,-684,-2832,792,84,
     J -536,-27,235,72,33,-46,17,2*0,449,-96,177,327,102,-326,128,86,83,
     K -9,-87,2*0,369,564,-109,-205,834,-108,-277,84,42,-37,-12,2*0,234,
     L 401,-424,63,-503,504,8,-57,0,-3,-33,2*0,-65,-238,249,-170,234,
     M -259,-130,101,49,-48,-33,2*0,-168,-114,58,123,94,40,60,-140,73,
     N 54,-21,2*0,1,39,-106,-9,-49,56,-67,-8,-148,-13,27,2*0,48,42,17,
     O -41,-22,21,1,-113,16,33,49,2*0,-14,-37,51,-2,4,-19,7,40,-53,31,
     P -75,28*0/
      DATA GTT4 /1,168*0/
      DATA G5 / 1, -30339,-1654,1297,958,-223,47,71,10,4*0,5758,-2123,
     A 2994,-2036,805,357,60,-54,9,4*0,-2006,130,1567,1289,492,246,4,0,
     B -3,4*0,-403,242,-176,843,-392,-26,-229,12,-12,4*0,149,-280,8,-265
     C ,256,-161,3,-25,-4,4*0,16,125,-123,-107,77,-51,-4,-9,7,4*0,-14,
     D 106,68,-32,-10,-13,-112,13,-5,4*0,-57,-27,-8,9,23,-19,-17,-2,12,
     E 4*0,3,-13,5,-17,4,22,-3,-16,6,56*0/
      DATA GT5 / 10, 153,-244,2,-7,19,-1,-5,1,4*0,-23,87,3,-108,2,11,-3,
     F -3,4,4*0,-118,-167,-16,7,-30,29,11,-7,6,4*0,42,7,-77,-38,-1,6,19,
     G -5,5*0,-1,16,29,-42,-21,0,-4,3,5*0,23,17,-24,8,-3,13,-4,0,-1,4*0,
     H-9,-4,20,-11,1,9,-2,-2,3,4*0,-11,3,4,2,4,2,3,-6,-3,4*0,1,-2,-3,-2,
     I -3,-4,-3,-3,-5,56*0/
      DATA GTT5 /1,168*0/
      DATA G6 / 1, -30375,-1648,1164,930,-179,42,77,11,4*0,5769,-2087,
     A 2954,-2033,811,357,55,-56,23,4*0,-1995,116,1579,1299,490,248,12,
     B 8,-6,4*0,-389,230,-141,880,-402,-20,-239,5,-17,4*0,142,-276,5,
     C -264,262,-171,16,-35,5,4*0,30,135,-123,-100,84,-64,8,-16,20,4*0,
     D -18,101,60,-32,-27,-12,-110,9,-1,4*0,-47,-35,-9,2,27,-17,-24,2,
     E 12,4*0,5,-7,3,-20,8,26,10,-12,7,56*0/
      DATA GT6 / 10, 155,-266,0,6,8,7*0,6,83,-13,-95,10,4,-5,6*0,-114,
     F -182,13,-19,-22,16,18,6*0,32,16,-85,-6,2,-3,14,6*0,30,-7,27,-27,
     G -30,-11,6,6*0,19,23,-18,14,5,17,2,6*0,-22,2,9,-21,-1,-2,-22,84*0/
      DATA GTT6 /1,168*0/
      DATA G7/10,-302059,-17917,12899,9475,-2145,460,734,121,107,-39,16,
     A -4,57446,-20664,29971,-20708,8009,3595,651,-546,77,57,-26,-31,30,
     B -20582,430,16086,12760,4579,2490,95,46,-32,23,7,-36,5,-3699,2456,
     C -1880,8334,-3960,-290,-2188,175,-124,-110,-19,37,-3,1617,-2758,
     D 185,-2788,2436,-1669,20,-210,-44,131,-15,-3,-13,157,1420,-1310,
     E -911,808,-582,-22,-32,45,33,74,-6,4,-171,1146,625,-323,-78,38,
     F -1125,143,34,2,46,-8,-14,-666,-265,-34,81,209,-240,-186,41,125,
     G 15,6,1,-12,121,-160,22,-176,46,189,-46,-187,94,9,-8,2,-12,-174,
     H 163,14,-27,-32,80,137,-4,-14,-4,22,-24,-1,27,19,0,35,-45,22,-31,
     I 56,-1,-63,14,4,10,-2,26,-26,-9,21,-1,18,-14,-28,-17,-14,6,-4,-3,
     J 4,9,-1,-10,26,-32,13,-6,-19,7,19,12/
      DATA GT7/10,231,-244,-19,-7,12,-7,0,3,4*0,-46,112,-1,-90,-6,7,6,
     K -3,3,4*0,-104,-166,40,-20,-36,12,14,3,4,4*0,72,21,-52,-54,-11,0,
     L 17,6,1,4*0,22,-5,14,-24,-23,-15,6,3,-1,4*0,1,25,-14,9,1,11,-3,2,
     M -3,4*0,-5,11,2,-3,7,22,-5,1,9,4*0,-17,-3,7,1,-2,-3,-2,-1,-2,4*0,
     N 2,-6,-3,-4,1,-2,-2,-1,6,56*0/
      DATA GTT7 /1,168*0/
      DATA SHMIT(1,1) / 0.0 /, TMOLD / 0.0 /, MODOLD / 0 /
C ***** SUBSCRIPTED DO-LOOP VERSION BEGINS HERE
      DIMENSION CONST(13,13),FN(13),FM(13)
      DIMENSION P(13,13),DP(13,13),SP(13),CP(13)
      DATA P(1,1),CP(1),DP(1,1),SP(1) / 2*1.,2*0. /
C ***** BEGIN PROGRAM
      IF(SHMIT(1,1).EQ.-1.)   GO TO 8
C ***** INITIALIZE * ONCE ONLY, FIRST TIME SUBROUTINE IS CALLED
      SHMIT(1,1)=-1.
      DO 18 N=1,13
      FN(N)=N
      DO 18 M=1,13
```

```
      FM(M)=M-1
   18 CONST(N,M) = FLOAT((N-2)**2-(M-1)**2) / ((2*N-3)*(2*N-5))
      DO 2 N=2,13
      SHMIT(N,1) = (2*N-3) * SHMIT(N-1,1) / (N-1)
      JJ=2
      DO 2 M=2,N
      SHMIT(N,M) = SHMIT(N,M-1) * SQRT(FLOAT((N-M+1)*JJ)/(N+M-2))
      SHMIT(M-1,N)=SHMIT(N,M)
    2 JJ = 1
      DO 7 K=1,7
      F1=LG(1,1,K)
      F2=LGT(1,1,K)
      F3=LGTT(1,1,K)
      NMAX=NMX(K)
      L = 0
      DO 3 I=1,3
    3 ISUM(K,I) = 0
      DO 4 N=1,NMAX
      DO 4 M=1,NMAX
      L = L+1
      ISUM(K,1)=ISUM(K,1)+L*LG(N,M,K)
      ISUM(K,2)=ISUM(K,2)+L*LGT(N,M,K)
    4 ISUM(K,3)=ISUM(K,3)+L*LGTT(N,M,K)
      DO 6 I=1,3
      IF(ISUM(K,I).EQ.LSUM(K,I))  GO TO 6
C   *****  ERROR IN DATA CARDS - NOTE WRITE AND STOP STATEMENTS
      PRINT 5,    K,I,LSUM(K,I),ISUM(K,I)
    5 FORMAT(///29H DATA WRONG IN ALLMAG--MODEL ,I2,3X,2HI=,I1,3X,
     A17HPRECALCULATED SUM,I10,3X,17HTHIS MACHINE GETS,I10)
      STOP
    6 CONTINUE
      DO 7 N=1,NMAX
      DO 7 M=1,NMAX
      GG(N,M,K)=LG(N,M,K)*SHMIT(N,M)/F1
      GGT(N,M,K)=LGT(N,M,K)*SHMIT(N,M)/F2
    7 GGTT(N,M,K)=LGTT(N,M,K)*SHMIT(N,M)/F3
    8 IF((MODEL.EQ.MODOLD).AND.(TM.EQ.TMOLD))  GO TO 11
C   *****  NOTE WRITE STATEMENT - NEW MODEL OR NEW TIME
      PRINT 9,    MODEL,(LABEL(I,MODEL),I=1,4),TM
    9 FORMAT('0 MODEL USED IS NUMBER',I2,2X,4A8,'  FOR TM =',F9.3/)
      IF(MODEL.LT.1.OR.MODEL.GT.7) STOP
      MODOLD=MODEL
      TMOLD=TM
      NMAX=NMX(MODEL)
      T=TM-TO(MODEL)
      DO 10 N=1,NMAX
      DO 10 M=1,NMAX
   10 G(N,M)=GG(N,M,MODEL)+T*(GGT(N,M,MODEL)+GGTT(N,M,MODEL)*T)
C   *****  CALCULATION USUALLY BEGINS HERE
   11 SP(2)=SPH
      CP(2)=CPH
      DO 12 M=3,NMAX
      SP(M)=SP(2)*CP(M-1)+CP(2)*SP(M-1)
   12 CP(M)=CP(2)*CP(M-1)-SP(2)*SP(M-1)
      AOR=6371.2/RKM
      AR=AOR**2
      BR=0.0
      BT=0.0
      BP=0.0
      DO 17 N=2,NMAX
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      AR=AOR*AR                                                         ALMGS482
      DO 17 M=1,N                                                       ALMGS484
      IF(M.EQ.N) GO TO 13                                               ALMGS486
      P(N,M)=CT*P(N-1,M)-CONST(N,M)*P(N-2,M)                            ALMGS488
      DP(N,M)=CT*DP(N-1,M)-ST*P(N-1,M)-CONST(N,M)*DP(N-2,M)             ALMGS490
      GO TO 14                                                          ALMGS492
   13 P(N,N)=ST*P(N-1,N-1)                                              ALMGS494
      DP(N,N)=ST*DP(N-1,N-1)+CT*P(N-1,N-1)                              ALMGS496
   14 PAR=P(N,M)*AR                                                     ALMGS498
      IF(M.EQ.1) GO TO 15                                               ALMGS500
      TEMP=G(N,M)*CP(M)+G(M-1,N)*SP(M)                                  ALMGS502
      BP=BP-(G(N,M)*SP(M)-G(M-1,N)*CP(M))*FM(M)*PAR                     ALMGS504
      GO TO 16                                                          ALMGS506
   15 TEMP = G(N,M)                                                     ALMGS508
   16 BR=BR-TEMP*FN(N)*PAR                                              ALMGS510
   17 BT=BT+TEMP*DP(N,M)*AR                                             ALMGS512
    1 BR = BR / 100000.                                                 ALMGS514
      BT = BT / 100000.                                                 ALMGS516
      BP = BP / ST / 100000.                                            ALMGS518
      B =  SQRT(BR*BR+BT*BT+BP*BP )                                     ALMGS520
C   FOR DOUBLE PRECISION REPLACE PRECEDING CARD WITH FOLLOWING CARD     ALMGS522
C     B = DSQRT(BR*BR+BT*BT+BP*BP )                                     ALMGS524
C   THIS AND THE IMPLICIT REAL*8 CARD ARE THE ONLY TWO CHANGES NEEDED.  ALMGS526
      RETURN                                                            ALMGS528
      END                                                               ALMGS530
                                                                          0265 CARDS
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      SUBROUTINE DEKMAG(MODEL,TM,RKM,ST,CT,SPH,CPH,BR,BT,BP,B)
C ****  THIS VERSION READS IN COEFFICIENTS AS DATA CARDS.  SEE BELOW.
C ****  GEOCENTRIC VERSION OF GEOMAGNETIC FIELD ROUTINE
C ****  SINGLE PRECISION DECK FOR IBM 360 MACHINES (EBCDIC, 029 PUNCH)
C ****  SHORT DECK, USES SUBSCRIPTED VARIABLES AND DO LOOPS
C ****  EXECUTION TIME PER CALL 3 TIMES GREATER THAN LONG DECK
C ****  PROGRAM DESIGNED AND TESTED BY E G STASSINOPOULOS AND G D MEAD,
C ****  CODE 641, NASA GODDARD SPACE FLT CTR, GREENBELT, MD 20771
C  *****  INPUT: MODEL    CHOICE OF 7 MODELS
C  *****         TM       TIME IN YEARS FOR DESIRED FIELD
C  *****         RKM      GEOCENTRIC DISTANCE IN KILOMETERS
C  *****         ST,CT    SIN & COS OF GEOCENTRIC COLATITUDE
C  *****         SPH,CPH  SIN & COS OF EAST LONGITUDE
C  ***** OUTPUT: BR,BT,BP GEOCENTRIC FIELD COMPONENTS IN GAUSS
C  *****         B        FIELD MAGNITUDE IN GAUSS
C  *****  NOTE: FOR GREATEST EFFICIENCY, COMPLETE ALL CALCULATIONS WITH
C               ONE MODEL AND ONE TIME BEFORE CHANGING MODELS OR TIME.
C  *****  FOR DOUBLE PRECISION ADD THE FOLLOWING CARD
C     IMPLICIT REAL*8(A-H,O-Z)
C  *****  SEE END OF DECK FOR ONE MORE CHANGE
      DIMENSION TO(7),NMX(7),G(13,13)
      REAL*8 LABEL(8,7)
      REAL*4     GG(13,13,7),GGT(13,13,7),GGTT(13,13,7),SHMIT(13,13)
      DATA SHMIT(1,1) / 0.0 /, TMOLD / 0.0 /, MODOLD / 0 /
      DIMENSION CONST(13,13),FN(13),FM(13)
      DIMENSION P(13,13),DP(13,13),SP(13),CP(13)
      DATA P(1,1),CP(1),DP(1,1),SP(1) / 2*1.,2*0. /
C  *****  BEGIN PROGRAM
      IF(SHMIT(1,1).EQ.-1.)    GO TO 8
C  *****  INITIALIZE * ONCE ONLY, FIRST TIME SUBROUTINE IS CALLED
      SHMIT(1,1)=-1.
      DO 18 N=1,13
      FN(N)=N
      DO 18 M=1,13
      FM(M)=M-1
      CONST(N,M) = FLOAT((N-2)**2-(M-1)**2) / ((2*N-3)*(2*N-5))
      DO 18 K=1,7
      GG(N,M,K) = 0.
      GGT(N,M,K) = 0.
   18 GGTT(N,M,K) = 0.
      DO 2 N=2,13
      SHMIT(N,1) = (2*N-3) * SHMIT(N-1,1) / (N-1)
      JJ=2
      DO 2 M=2,N
      SHMIT(N,M) = SHMIT(N,M-1) * SQRT(FLOAT((N-M+1)*JJ)/(N+M-2))
      SHMIT(M-1,N)=SHMIT(N,M)
    2 JJ = 1
C  COEFFICIENTS ARE READ IN WHEN DEKMAG IS CALLED THE FIRST TIME
C  SET UP INPUT DECK AS FOLLOWS:
C  CARD 1. NMODLS,NPRINT (2I5).  NMODLS = NO. OF MODLS TO BE READ IN
C  DECK A: FIRST MODEL IN STANDARD CAIN FORMAT.
C  DECK B: SECOND MODEL, ETC.
C  FIRST CARD IN EACH DECK CONTAINS EPOCH (COLS 4-9) AND LABEL (10-73).
C  LAST CARD IN EACH MODEL DECK CONTAINS ZERO OR BLANK IN COLS 1-3.
      READ(5,4) NMODLS,NPRINT
    4 FORMAT(2I5)
      IF(NMODLS.GT.7) NMODLS = 7
      DO 3 K=1,NMODLS
      READ(5,20) TZ,(LABEL(I,K),I=1,8)
   20 FORMAT(3X,F6.1,8A8)
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      WRITE(6,21) K,(LABEL(I,K),I=1,8)                                  DEKMG122
   21 FORMAT('0 MODEL NUMBER'I3,5X,8A8)                                 DEKMG124
      MAXN=0                                                            DEKMG126
5     READ (5,6) N,M,GNM,HNM,GTNM,HTNM,GTTNM,HTTNM                      DEKMG128
6     FORMAT (2I3,6F11.4)                                               DEKMG130
      IF (N.LE.0) GOTO7                                                 DEKMG132
      IF(NPRINT.EQ.1) WRITE(6,6)N,M,GNM,HNM,GTNM,HTNM,GTTNM,HTTNM       DEKMG134
      MAXN=(MAX0(N,MAXN))                                               DEKMG136
      GG(N,M,K) = GNM                                                   DEKMG138
      GGT(N,M,K) = GTNM                                                 DEKMG140
      GGTT(N,M,K) = GTTNM                                               DEKMG142
      IF (M.EQ.1) GOTO5                                                 DEKMG144
      GG(M-1,N,K) = HNM                                                 DEKMG146
      GGT(M-1,N,K) = HTNM                                               DEKMG148
      GGTT(M-1,N,K) = HTTNM                                             DEKMG150
      GO TO 5                                                           DEKMG152
    7 CONTINUE                                                          DEKMG154
      IF(NPRINT.EQ.0) WRITE(6,22) GG(2,1,K)                             DEKMG156
   22 FORMAT('   G(2,1) ='F9.1)                                         DEKMG158
      NMX(K) = MAXN                                                     DEKMG160
      TO(K) = TZ                                                        DEKMG162
      DO 3 N=1,MAXN                                                     DEKMG164
      DO 3 M=1,MAXN                                                     DEKMG166
      GG(N,M,K) = GG(N,M,K) * SHMIT(N,M)                                DEKMG168
      GGT(N,M,K) = GGT(N,M,K) * SHMIT(N,M)                              DEKMG170
    3 GGTT(N,M,K) = GGTT(N,M,K) * SHMIT(N,M)                            DEKMG172
    8 IF((MODEL.EQ.MODOLD).AND.(TM.EQ.TMOLD))  GO TO 11                 DEKMG174
C  *****  NOTE WRITE STATEMENT - NEW MODEL OR NEW TIME                  DEKMG176
      PRINT 9,    MODEL,(LABEL(I,MODEL),I=1,8),TM                       DEKMG178
    9 FORMAT('0 MODEL USED IS NUMBER',I2,2X,8A8,'  FOR TM =',F9.3/)     DEKMG180
      IF(MODEL.LT.1.OR.MODEL.GT.NMODLS) STOP                            DEKMG182
      MODOLD=MODEL                                                      DEKMG184
      TMOLD=TM                                                          DEKMG186
      NMAX=NMX(MODEL)                                                   DEKMG188
      T=TM-TO(MODEL)                                                    DEKMG190
      DO 10 N=1,NMAX                                                    DEKMG192
      DO 10 M=1,NMAX                                                    DEKMG194
   10 G(N,M)=GG(N,M,MODEL)+T*(GGT(N,M,MODEL)+GGTT(N,M,MODEL)*T)         DEKMG196
C  *****  CALCULATION USUALLY BEGINS HERE                               DEKMG198
   11 SP(2)=SPH                                                         DEKMG200
      CP(2)=CPH                                                         DEKMG202
      DO 12 M=3,NMAX                                                    DEKMG204
      SP(M)=SP(2)*CP(M-1)+CP(2)*SP(M-1)                                 DEKMG206
   12 CP(M)=CP(2)*CP(M-1)-SP(2)*SP(M-1)                                 DEKMG208
      AOR=6371.2/RKM                                                    DEKMG210
      AR=AOR**2                                                         DEKMG212
      BR=0.0                                                            DEKMG214
      BT=0.0                                                            DEKMG216
      BP=0.0                                                            DEKMG218
      DO 17 N=2,NMAX                                                    DEKMG220
      AR=AOR*AR                                                         DEKMG222
      DO 17 M=1,N                                                       DEKMG224
      IF(M.EQ.N) GO TO 13                                               DEKMG226
      P(N,M)=CT*P(N-1,M)-CONST(N,M)*P(N-2,M)                            DEKMG228
      DP(N,M)=CT*DP(N-1,M)-ST*P(N-1,M)-CONST(N,M)*DP(N-2,M)             DEKMG230
      GO TO 14                                                          DEKMG232
   13 P(N,N)=ST*P(N-1,N-1)                                              DEKMG234
      DP(N,N)=ST*DP(N-1,N-1)+CT*P(N-1,N-1)                              DEKMG236
   14 PAR=P(N,M)*AR                                                     DEKMG238
      IF(M.EQ.1) GO TO 15                                               DEKMG240
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      TEMP=G(N,M)*CP(M)+G(M-1,N)*SP(M)                                  DEKMG242
      BP=BP-(G(N,M)*SP(M)-G(M-1,N)*CP(M))*FM(M)*PAR                     DEKMG244
      GO TO 16                                                          DEKMG246
   15 TEMP = G(N,M)                                                     DEKMG248
   16 BR=BR-TEMP*FN(N)*PAR                                              DEKMG250
   17 BT=BT+TEMP*DP(N,M)*AR                                             DEKMG252
    1 BR = BR / 100000.                                                 DEKMG254
      BT = BT / 100000.                                                 DEKMG256
      BP = BP / ST / 100000.                                            DEKMG258
      B =  SQRT(BR*BR+BT*BT+BP*BP )                                     DEKMG260
C   FOR DOUBLE PRECISION REPLACE PRECEDING CARD WITH FOLLOWING CARD     DEKMG262
C     B = DSQRT(BR*BR+BT*BT+BP*BP )                                     DEKMG264
C   THIS AND THE IMPLICIT REAL*8 CARD ARE THE ONLY TWO CHANGES NEEDED.  DEKMG266
      RETURN                                                            DEKMG268
      END                                                               DEKMG270
                                                                             0135 CARDS
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```
      SUBROUTINE ONEMAG(TM,RKM,ST,CT,SPH,CPH,BR,BT,BP,B)                ONEMG002
C ****  THIS VERSION CONTAINS ONE MODEL ONLY - IGRF 1965.0              ONEMG004
C ****  GEOCENTRIC VERSION OF GEOMAGNETIC FIELD ROUTINE                 ONEMG006
C ****  SINGLE PRECISION DECK FOR IBM 360 MACHINES (EBCDIC, 029 PUNCH)  ONEMG008
C ****  SHORT DECK, USES SUBSCRIPTED VARIABLES AND DO LOOPS             ONEMG010
C ****  PROGRAM DESIGNED AND TESTED BY G D MEAD, CODE 641, GSFC         ONEMG012
C  *****  INPUT: TM       TIME IN YEARS FOR DESIRED FIELD               ONEMG014
C  *****         RKM      GEOCENTRIC DISTANCE IN KILOMETERS             ONEMG016
C  *****         ST,CT    SIN & COS OF GEOCENTRIC COLATITUDE            ONEMG018
C  *****         SPH,CPH  SIN & COS OF EAST LONGITUDE                   ONEMG020
C  ***** OUTPUT: BR,BT,BP GEOCENTRIC FIELD COMPONENTS IN GAUSS          ONEMG022
C  *****         B        FIELD MAGNITUDE IN GAUSS                      ONEMG024
C  *****  FOR DOUBLE PRECISION ADD THE FOLLOWING CARD                   ONEMG026
C      IMPLICIT REAL*8(A-H,O-Z)                                         ONEMG028
C  *****  SEE END OF DECK FOR ONE MORE CHANGE                           ONEMG030
      DIMENSION LG(13,13),LGT(13,13),G(13,13),GG(13,13),GGT(13,13),     ONEMG032
     1 SHMIT(13,13)                                                     ONEMG034
      EQUIVALENCE (LG(1,1),GG(1,1)),(LGT(1,1),GGT(1,1))                 ONEMG036
      DATA SHMIT(1,1)/0./,TMOLD/0./,TZERO/1965./,NMAX/9/                ONEMG038
      DATA LG / 1, -30339,-1654,1297,958,-223,47,71,10,4*0,5758,-2123,  ONEMG040
     A 2994,-2036,805,357,60,-54,9,4*0,-2006,130,1567,1289,492,246,4,0, ONEMG042
     B -3,4*0,-403,242,-176,843,-392,-26,-229,12,-12,4*0,149,-280,8,-265ONEMG044
     C ,256,-161,3,-25,-4,4*0,16,125,-123,-107,77,-51,-4,-9,7,4*0,-14,  ONEMG046
     D 106,68,-32,-10,-13,-112,13,-5,4*0,-57,-27,-8,9,23,-19,-17,-2,12, ONEMG048
     E 4*0,3,-13,5,-17,4,22,-3,-16,6,56*0/                              ONEMG050
      DATA LGT / 10, 153,-244,2,-7,19,-1,-5,1,4*0,-23,87,3,-108,2,11,-3,ONEMG052
     F -3,4,4*0,-118,-167,-16,7,-30,29,11,-7,6,4*0,42,7,-77,-38,-1,6,19,ONEMG054
     G -5,5*0,-1,16,29,-42,-21,0,-4,3,5*0,23,17,-24,8,-3,13,-4,0,-1,4*0,ONEMG056
     H-9,-4,20,-11,1,9,-2,-2,3,4*0,-11,3,4,2,4,2,3,-6,-3,4*0,1,-2,-3,-2,ONEMG058
     I -3,-4,-3,-3,-5,56*0/                                             ONEMG060
      DIMENSION CONST(13,13),FN(13),FM(13)                              ONEMG062
      DIMENSION P(13,13),DP(13,13),SP(13),CP(13)                        ONEMG064
      DATA P(1,1),CP(1),DP(1,1),SP(1) / 2*1.,2*0. /                     ONEMG066
      IF(SHMIT(1,1).EQ.-1.)   GO TO 8                                   ONEMG068
C  *****  INITIALIZE * ONCE ONLY, FIRST TIME SUBROUTINE IS CALLED       ONEMG070
      SHMIT(1,1)=-1.                                                    ONEMG072
      DO 18 N=1,13                                                      ONEMG074
      FN(N)=N                                                           ONEMG076
      DO 18 M=1,13                                                      ONEMG078
      FM(M)=M-1                                                         ONEMG080
   18 CONST(N,M) = FLOAT((N-2)**2-(M-1)**2) / ((2*N-3)*(2*N-5))         ONEMG082
      DO 2 N=2,13                                                       ONEMG084
      SHMIT(N,1) = (2*N-3) * SHMIT(N-1,1) / (N-1)                       ONEMG086
      JJ=2                                                              ONEMG088
      DO 2 M=2,N                                                        ONEMG090
      SHMIT(N,M) = SHMIT(N,M-1) * SQRT(FLOAT((N-M+1)*JJ)/(N+M-2))       ONEMG092
      SHMIT(M-1,N)=SHMIT(N,M)                                           ONEMG094
    2 JJ = 1                                                            ONEMG096
      F1 = LG(1,1)                                                      ONEMG098
      F2 = LGT(1,1)                                                     ONEMG100
      DO 7 N=1,NMAX                                                     ONEMG102
      DO 7 M=1,NMAX                                                     ONEMG104
      GG(N,M) = LG(N,M)*SHMIT(N,M)/F1                                   ONEMG106
    7 GGT(N,M) = LGT(N,M)*SHMIT(N,M)/F2                                 ONEMG108
    8 IF(TM.EQ.TMOLD) GO TO 11                                          ONEMG110
      TMOLD=TM                                                          ONEMG112
      T = TM - TZERO                                                    ONEMG114
      DO 10 N=1,NMAX                                                    ONEMG116
      DO 10 M=1,NMAX                                                    ONEMG118
   10 G(N,M) = GG(N,M) + T*GGT(N,M)                                     ONEMG120
```

```
C   *****  CALCULATION USUALLY BEGINS HERE                                ONEMG122
   11 SP(2)=SPH                                                           ONEMG124
      CP(2)=CPH                                                           ONEMG126
      DO 12 M=3,NMAX                                                      ONEMG128
      SP(M)=SP(2)*CP(M-1)+CP(2)*SP(M-1)                                   ONEMG130
   12 CP(M)=CP(2)*CP(M-1)-SP(2)*SP(M-1)                                   ONEMG132
      AOR=6371.2/RKM                                                      ONEMG134
      AR=AOR**2                                                           ONEMG136
      BR=0.0                                                              ONEMG138
      BT=0.0                                                              ONEMG140
      BP=0.0                                                              ONEMG142
      DO 17 N=2,NMAX                                                      ONEMG144
      AR=AOR*AR                                                           ONEMG146
      DO 17 M=1,N                                                         ONEMG148
      IF(M.EQ.N) GO TO 13                                                 ONEMG150
      P(N,M)=CT*P(N-1,M)-CONST(N,M)*P(N-2,M)                              ONEMG152
      DP(N,M)=CT*DP(N-1,M)-ST*P(N-1,M)-CONST(N,M)*DP(N-2,M)               ONEMG154
      GO TO 14                                                            ONEMG156
   13 P(N,N)=ST*P(N-1,N-1)                                                ONEMG158
      DP(N,N)=ST*DP(N-1,N-1)+CT*P(N-1,N-1)                                ONEMG160
   14 PAR=P(N,M)*AR                                                       ONEMG162
      IF(M.EQ.1) GO TO 15                                                 ONEMG164
      TEMP=G(N,M)*CP(M)+G(M-1,N)*SP(M)                                    ONEMG166
      BP=BP-(G(N,M)*SP(M)-G(M-1,N)*CP(M))*FM(M)*PAR                       ONEMG168
      GO TO 16                                                            ONEMG170
   15 TEMP = G(N,M)                                                       ONEMG172
   16 BR=BR-TEMP*FN(N)*PAR                                                ONEMG174
   17 BT=BT+TEMP*DP(N,M)*AR                                               ONEMG176
      BP = BP/ST/100000.                                                  ONEMG178
      BR = BR/100000.                                                     ONEMG180
      BT = BT/100000.                                                     ONEMG182
      B =  SQRT(BR*BR+BT*BT+BP*BP )                                       ONEMG184
C   FOR DOUBLE PRECISION REPLACE PRECEDING CARD WITH FOLLOWING CARD       ONEMG186
C     B = DSQRT(BR*BR+BT*BT+BP*BP )                                       ONEMG188
C   THIS AND THE IMPLICIT REAL*8 CARD ARE THE ONLY TWO CHANGES NEEDED.    ONEMG190
      RETURN                                                              ONEMG192
      END                                                                 ONEMG194
                                                                              0097 CARDS
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```
C ****  STANDARD CALLING ROUTINE FOR GDALMG
C **** SINGLE PRECISION DECK FOR IBM 360 MACHINES (EBCDIC, 029 PUNCH)
C ****  NEEDS SINGLE-PRECISION SUBROUTINES GDALMG AND ALLMAG
      REAL*4 TM(2)/1965.,1970./,GDLAT(2)/-30.,60./,GLON(2)/-90.,90./,
     1   ALT/100./
      PRINT 10
   10 FORMAT('1 MODEL     TIME      LAT      LONG     ALT         X           Y
     1           Z          F         H         DEC        INC')
      DO 20 MODEL=1,7
      DO 20 I=1,2
      DO 20 J=1,2
      DO 20 K=1,2
      CALL GDALMG(MODEL,TM(I),GDLAT(J),GLON(K),ALT,X,Y,Z,F,H,DEC,AINC)
   20 PRINT 30,    MODEL,TM(I),GDLAT(J),GLON(K),ALT,X,Y,Z,F,H,DEC,AINC
   30 FORMAT(I5,3X,4F8.0,5F10.5,2F10.2)
      STOP
      END
                                                                    0017 CARDS
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      SUBROUTINE GDALMG(MODEL,TM,GDLAT,GDLON,GDALT,X,Y,Z,F,H,DEC,AINC)  GDALM002
C ****  GEODETIC VERSION OF GEOMAGNETIC FIELD SUBROUTINE                 GDALM004
C ****  SINGLE PRECISION DECK FOR IBM 360 MACHINES (EBCDIC, 029 PUNCH)   GDALM006
C ****  NEEDS SINGLE-PRECISION SUBROUTINE ALLMAG                         GDALM008
C ****  PROGRAM DESIGNED AND TESTED BY G D MEAD AND E G STASSINOPOULOS,  GDALM010
C ****  CODE 641, NASA GODDARD SPACE FLT CTR, GREENBELT, MD 20771        GDALM012
C***INPUT:  MODEL = 1-7; CHOICE OF SEVEN MODELS - SEE ALLMAG             GDALM014
C           TM = TIME IN YEARS FOR DESIRED FIELD (E.G. 1971.25)          GDALM016
C           GDLAT = GEODETIC LATITUDE (DEGREES)                          GDALM018
C           GDLON = EAST LONGITUDE (DEGREES)                             GDALM020
C           GDALT = ALTITUDE ABOVE GEOID (KMS)                           GDALM022
C***OUTPUT: X,Y,Z = GEODETIC FIELD COMPONENTS (GAUSS)                    GDALM024
C           F = MAGNITUDE OF FIELD (GAUSS)                               GDALM026
C           H = HORIZONTAL INTENSITY (GAUSS)                             GDALM028
C           DEC, AINC = DECLINATION AND INCLINATION ANGLES (DEGREES)     GDALM030
C***  NOTE: FOR GREATEST EFFICIENCY, COMPLETE ALL CALCULATIONS WITH ONE  GDALM032
C     MODEL AND ONE TIME BEFORE CHANGING MODEL OR TIME.                  GDALM034
C   REFERENCE GEOID IS THAT ADOPTED BY IAU IN 1964                       GDALM036
      DATA RAD,A,AB2,E2/57.29578,6378.16,1.0067397,.0067397/             GDALM038
      SINLAT =  SIN(GDLAT/RAD)                                           GDALM040
      COSLAT =  SQRT(1.-SINLAT**2)                                       GDALM042
      IF(MODEL.EQ.6) GO TO 2                                             GDALM044
    1 SINBET = SINLAT / SQRT(SINLAT**2+(AB2*COSLAT)**2)                  GDALM046
C***   BETA = GEOCENTRIC LATITUDE AT SURFACE OF GEOID                    GDALM048
      COSBET = SQRT(1.-SINBET*SINBET)                                    GDALM050
      RGEOID = A / SQRT(1.+E2*SINBET*SINBET)                             GDALM052
      XKM = RGEOID*COSBET + GDALT*COSLAT                                 GDALM054
      YKM = RGEOID*SINBET + GDALT*SINLAT                                 GDALM056
      RKM =  SQRT(XKM**2+YKM**2)                                         GDALM058
      ST = XKM/RKM                                                       GDALM060
      CT = YKM/RKM                                                       GDALM062
      GO TO 3                                                            GDALM064
    2 RKM = 6371.2 + GDALT                                               GDALM066
      ST = COSLAT                                                        GDALM068
      CT = SINLAT                                                        GDALM070
    3 SP =  SIN(GDLON/RAD)                                               GDALM072
      CP =  COS(GDLON/RAD)                                               GDALM074
      CALL ALLMAG(MODEL,TM,RKM,ST,CT,SP,CP,BR,BT,Y,F)                    GDALM076
      SIND = ST*SINLAT - CT*COSLAT                                       GDALM078
      COSD = CT*SINLAT + ST*COSLAT                                       GDALM080
      X = -BT*COSD - BR*SIND                                             GDALM082
      Z =  BT*SIND - BR*COSD                                             GDALM084
      H =  SQRT(X*X+Y*Y)                                                 GDALM086
      DEC = RAD *  ATAN2(Y,X)                                            GDALM088
      AINC = RAD *  ATAN(Z/H)                                            GDALM090
      RETURN                                                             GDALM092
      END                                                                GDALM094
                                                                           0047 CARDS
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C  *****  MAIN DECK FOR LINTRA
C  *****  MODIFIED FIELD LINE TRACING ROUTINE AS OF JAN 1971,
C  *****  DESIGNED AND TESTED BY E G STASSINOPOULOS AND G D MEAD,
C  *****  CODE 641, NASA GODDARD SPACE FLT CTR, GREENBELT, MD 20771
C  *****  SINGLE PRECISION DECK FOR IBM 360 MACHINES (EBCDIC, 029 PUNCH)
C  *****  NEEDS SINGLE-PRECISION SUBROUTINES CONVRT, ITERAT, AND ALLMAG.
C  *****  ACCEPTING INPUT COORDINATES OF STARTING POINTS IN EITHER A
C  *****  GEOCENTRIC OR GEODETIC SYSTEM AND RETURNING COORDINATES
C  *****  FOR CONJUGATE INTERSECT POSITIONS IN BOTH SYSTEMS.
C  *****  INTERSECTS MAY BE OBTAINED AT ANY SPECIFIED ALTITUDE LEVEL.
C  *****  DIRECTION OF TRACING INPUT-CONTROLLED THROUGH PARAMETER "DIR".
C  *****  FOR SURFACE POINTS "DIR" SHOULD ALWAYS BE (+1).
C  *****  FOR SPACE POINTS, (DIR>0) WILL TRACE THE FIELD LINE TO THE
C  *****  OPPOSITE HEMISPHERE, (DIR<0) WILL TRACE THE FIELD LINE TOWARDS
C  *****  THE SURFACE IN THE SAME HEMISPHERE.
C  ***** INPUT:  MODEL            CHOICE OF 7 MODELS (FROM ALLMAG)
C  *****         TM               TIME IN YEARS FOR DESIRED FIELD
C  *****         NPRINT           PARAMETER CONTROLLING OUTPUT
C  *****                          =0 NO RUNNING PRINTOUT; =1 PRINT STEPS
C  *****         ICOORD           REFERENCE SYSTEM OF INPUT COORDINTATES
C  *****                          =1 GEODETIC;  =2 GEOCENTRIC
C  *****         GDLAT,GLON,ALT GEODETIC STARTING POINT COORD(DEGR.,KM)
C  *****         GCLAT,GLON,RKM GEOCENTRIC STARTING POINT COORD( "  ," )
C  *****         DS               TRACING STEPSIZE IN KILOMETERS
C  *****         DIR              PARAMETER CONTROLLING DIRECTION OF TRACE
C  *****                          +1. STARTS TRACING TOWARDS HIGHER ALT.
C  *****                          -1. STARTS TRACING TOWARDS LOWER ALT.
C  *****         HALT             GEODETIC ALTITUDE OF CONJUGATE INTERSECT
C  *****         LABEL            NAME OF ORIGIN (STARTING POINT)
C  *****OUTPUT:  PLAT,PLON,PRKM GEOCENTRIC COORD. OF CONJUGATE INTERSECT
C  *****         PGLAT,PLON,PALT GEODETIC COORD. OF CONJUGATE INTERSECT
C  *****         ARC              ARCLENGTH OF FIELD LINE TRACED, IN KM
C  *****         BMIN             MINIMUM FIELD STRENGTH ALONG LINE
C  *****         BMINLT,BMINLN, GEOCENTRIC COORD. OF BMIN POSITION, IN
C  *****              BMINR       DEGREES AND KILOMETERS
      COMMON /ITER/  L,R,DLAT,DLON,RP,DLATP,DLONP,BR,BT,BP,B,ST,SGN,DS
      DATA RAD/57.2957795/, C1/.0067397/, RA/6378.16/, MAXS/200/
   10 FORMAT(6F10.6,2A4)
   11 FORMAT('0',47X,'STEP',7X,'LAT',5X,'LON',4X,'RKM',3X,'ALT',7X,'BR',
     16X,'BT',6X,'BP',7X,'B',/)
   12 FORMAT(20X,'OLD COORDINATES FOR STEP#',I6,' **',2F9.3,2F8.0,4F9.5)
   13 FORMAT('1MODEL ',I8/,' TIME ',F9.2/,' PRINT ',I8/,' COORD ',I8,/)
   14 FORMAT(10X,'GEOCENTRIC COORDINATES    GEODETIC COORDINATES     STEP
     1SIZE/ARCLENGTH    DIR    HALT    LABEL',/,12X,'LAT     LONG     RKM',
     27X,'LAT    LONG     ALT',9X,'DS/ARC',/,11X,'(DEGR) (DEGR)   (KM)',
     36X,'(DEGR) (DEGR)  (KM)',9X,'(KM)',/)
   15 FORMAT(' ORIGIN ',2F8.2,F8.1,1X2F8.2,F8.1,F11.0,9X,2F7.0,5X,2A4)
   16 FORMAT(I5,F10.2,2I5)
   17 FORMAT('0INTRSCT  ',F6.2,F8.2,F8.1,1X,2F8.2,F8.1,F11.0,////)
   18 FORMAT(' CHECK INPUT: ALT=',F8.0,9X,'DIR=',F3.0,9X,'HALT=',F8.0//)
   19 FORMAT('0LINE TRACING TERMINATED: ITERATION EXCEEDS 200 STEPS',//)
      PINTER(A1,A2,A3,A4,A5,A6,A7) = ((A2-A3)*(A7-A2)*(A7-A3)*A4-(A1-A3)
     1 *(A7-A1)*(A7-A3)*A5+(A1-A2)*(A7-A1)*(A7-A2)*A6)/((A1-A2)*(A1-A3)
     2 *(A2-A3))
      READ(5,16,END=6)  MODEL,TM,NPRINT,ICOORD
      WRITE(6,13) MODEL,TM,NPRINT,ICOORD
      IF(NPRINT.EQ.0) WRITE(6,14)
      IF(ICOORD.EQ.2) GO TO 2
    1 READ(5,10,END=6)  GDLAT,GLON,ALT,DS,DIR,HALT,LABEL1,LABEL2
      CALL CONVRT(1,GDLAT,ALT,GCLAT,RKM)
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```
      GO TO 3
    2 READ(5,10,END=6)  GCLAT,GLON,RKM,DS,DIR,HALT,LABEL1,LABEL2
      CALL CONVRT(2,GDLAT,ALT,GCLAT,RKM)
    3 IF(NPRINT.EQ.1) WRITE(6,14)
      SINGML=.98*SIN(GCLAT/RAD)+.199*COS(GCLAT/RAD)*COS((GLON+69.)/RAD)
      DS = .06*RKM/(1.-SINGML**2) - 370.
      IF(DS.GT.3.E3) DS=3.E3
      IF((DIR.LT.0.).AND.(DS.GT.(ALT-HALT)/20.)) DS=(ALT-HALT)/20.
      WRITE(6,15)GCLAT,GLON,RKM,GDLAT,GLON,ALT,DS,DIR,HALT,LABEL1,LABEL2
      IF(ALT+DIR*HALT.GE. 0.0) GO TO 7
      WRITE(6,18) ALT,DIR,HALT
      GO TO (1,2),ICOORD
    7 IF(NPRINT.EQ.1) WRITE(6,11)
      BMIN=5.0
      DLAT=GCLAT
      DLON=GLON
      R=RKM
      L=0
    4 CT=SIN(DLAT/RAD)
      ST=SQRT(1.-CT*CT)
      SP=SIN(DLON/RAD)
      CP=COS(DLON/RAD)
      CALL ALLMAG(MODEL,TM,R,ST,CT,SP,CP,BR,BT,BP,B)
      IF(L.EQ.0) SGN=SIGN(1.,BR*DIR)
      IF(BMIN.LE.B) GO TO 5
      BMIN=B
      BMINLT=DLAT
      BMINLN=DLON
      BMINR=R
    5 L=L+1
      IF(L.LT.MAXS) GO TO 8
      WRITE(6,19)
      GO TO (1,2),ICOORD
    8 DLATPP=DLATP
      DLONPP=DLONP
      CALL ITERAT
      HPP=HP
      HP=RP-RA/SQRT(1.+C1*CT*CT)
      IF(NPRINT.EQ.1) WRITE(6,12) L,DLATP,DLONP,RP,HP,BR,BT,BP,B
      IF(R.GT.RP) GO TO 4
      H=R-RA/SQRT(1.+C1*SIN(DLAT/RAD)**2)
      IF(H.GT.HALT) GO TO 4
      PLAT=PINTER(HPP,HP,H,DLATPP,DLATP,DLAT,HALT)
      PLON=PINTER(HPP,HP,H,DLONPP,DLONP,DLON,HALT)
      PRKM=HALT+RA/SQRT(1.+C1*SIN(PLAT/RAD)**2)
      ARC=DS*((L-5)+(HP-HALT)/(HP-H))
      IF(PLON.LT.-180.0) PLON=PLON+360.0
      IF(PLON.GT.180.0) PLON=PLON-360.0
      CALL CONVRT(2,PGDLAT,PGALT,PLAT,PRKM)
      WRITE(6,17) PLAT,PLON,PRKM,PGDLAT,PLON,PGALT,ARC
      GO TO (1,2) ,ICOORD
    6 STOP
      END
```

0113 CARDS

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      SUBROUTINE ITERAT                                                 ITRAT002
C***  SINGLE PRECISION DECK FOR IBM 360 MACHINES (EBCDIC, 029 PUNCH)    ITRAT004
C***  FIELD LINE INTEGRATION PROGRAM USING A 4-POINT ADAMS FORMULA AFTERITRAT006
C***  INITIALIZATION.  FIRST 7 ITERATIONS ADVANCE POINT BY 3*DS         ITRAT008
C*** INPUT: L                          STEP COUNT.  SET L=1 FIRST TIME THRU; ITRAT010
C***                                   SET L=L+1 THEREAFTER.            ITRAT012
C***         Y(1-3): R,DLAT,DLON       GEOCENTR TRACING POINT COORD.(KM,DEGR)ITRAT014
C***         B,BR,BT,BP                FIELD & COMPONENTS AT POINT Y(1-3)   ITRAT016
C***         ST                        SINE OF GEOCENTRIC COLATITUDE    ITRAT018
C***         SGN                       SGN=+1: TRACES IN DIRECTION OF FIELD  ITRAT020
C***                                   SGN=-1: TRACES OPPOSITE TO FIELD DIRECITRAT022
C***         DS                        INTERGR.STEPSIZE (ARC INCREMENT) IN KMITRAT024
C***OUTPUT: Y(1-3): R,DLAT,DLON        NEW IMPLEMENTED TRACING POINT COORD   ITRAT026
C***         YOLD(1-3): RP,DLATP,DLONP OLD Y(1-3), BEFORE IMPLEMENTATION ITRAT028
      COMMON /ITER/  L,Y,YOLD,BR,BT,BP,B,ST,SGN,DS                      ITRAT030
      DIMENSION Y(3),YOLD(3),YP(3,4)                                    ITRAT032
      DATA RAD /57.2957795/                                             ITRAT034
      YP(1,4)=SGN*(BR/B)                                                ITRAT036
      FAC=SGN*RAD/(B*Y(1))                                              ITRAT038
      YP(2,4)=-BT*FAC                                                   ITRAT040
      YP(3,4)=BP*FAC/ST                                                 ITRAT042
      IF(L.GT.7) GO TO 9                                                ITRAT044
      DO 8 I=1,3                                                        ITRAT046
      GO TO(1,2,3,4,5,6,7),L                                            ITRAT048
    1 D2=DS/2.                                                          ITRAT050
      D6=DS/6.                                                          ITRAT052
      D12=DS/12.                                                        ITRAT054
      D24=DS/24.                                                        ITRAT056
      YP(I,1) = YP(I,4)                                                 ITRAT058
      YOLD(I) = Y(I)                                                    ITRAT060
      Y(I) = YOLD(I) + DS* YP(I,1)                                      ITRAT062
      GO TO 8                                                           ITRAT064
    2 YP(I,2) = YP(I,4)                                                 ITRAT066
      Y(I) = YOLD(I) + D2 * (YP(I,2) + YP(I,1))                         ITRAT068
      GO TO 8                                                           ITRAT070
    3 Y(I) = YOLD(I) + D6 * (2.*YP(I,4) + YP(I,2) + 3.*YP(I,1))         ITRAT072
      GO TO 8                                                           ITRAT074
    4 YP(I,2) = YP(I,4)                                                 ITRAT076
      YOLD(I) = Y(I)                                                    ITRAT078
      Y(I) = YOLD(I) + D2 * (3.*YP(I,2) - YP(I,1))                      ITRAT080
      GO TO 8                                                           ITRAT082
    5 Y(I) = YOLD(I) + D12 * (5.*YP(I,4) + 8.*YP(I,2) - YP(I,1))        ITRAT084
      GO TO 8                                                           ITRAT086
    6 YP(I,3) = YP(I,4)                                                 ITRAT088
      YOLD(I) = Y(I)                                                    ITRAT090
      Y(I) = YOLD(I) + D12 * (23.*YP(I,3) - 16.*YP(I,2) + 5.*YP(I,1))   ITRAT092
      GO TO 8                                                           ITRAT094
    7 Y(I)=YOLD(I)+D24*(9.*YP(I,4)+19.*YP(I,3)-5.*YP(I,2)+YP(I,1))      ITRAT096
    8 CONTINUE                                                          ITRAT098
      RETURN                                                            ITRAT100
    9 DO 10 I=1,3                                                       ITRAT102
      YOLD(I) = Y(I)                                                    ITRAT104
      Y(I)=YOLD(I)+D24*(55.*YP(I,4)-59.*YP(I,3)+37.*YP(I,2)-9.*YP(I,1)) ITRAT106
      DO 10 J=1,3                                                       ITRAT108
   10 YP(I,J) = YP(I,J+1)                                               ITRAT110
      RETURN                                                            ITRAT112
      END                                                               ITRAT114
                                                                             0057 CARDS
```

```
      SUBROUTINE CONVRT(I,GDLAT,ALT,GCLAT,RKM)                          CNVRT002
C  SINGLE PRECISION DECK FOR IBM 360 MACHINES (EBCDIC, 029 PUNCH)       CNVRT004
C  CONVERTS SPACE POINT FROM GEODETIC TO GEOCENTRIC OR VICE VERSA       CNVRT006
C  REFERENCE GEOID IS THAT ADOPTED BY IAU IN 1964                       CNVRT008
C  A=6378.16, B=6356.7746, F=1/298.25                                   CNVRT010
C  I = 1  GEODETIC TO GEOCENTRIC                                        CNVRT012
C  I = 2  GEOCENTRIC TO GEODETIC                                        CNVRT014
C  GDLAT = GEODETIC LATITUDE IN DEGREES                                 CNVRT016
C  ALT = ALTITUDE ABOVE GEOID IN KILOMETERS                             CNVRT018
C  GCLAT = GEOCENTRIC LATITUDE IN DEGREES                               CNVRT020
C  RKM = GEOCENTRIC DISTANCE IN KILOMETERS                              CNVRT022
      DATA A,RAD,AB2,EP2/6378.16,57.29578,1.0067397,.0067397/           CNVRT024
      IF(I.EQ.2) GO TO 2                                                CNVRT026
    1 SINLAT = SIN(GDLAT/RAD)                                           CNVRT028
      COSLAT = SQRT(1.-SINLAT**2)                                       CNVRT030
      COSTH = SINLAT / SQRT((AB2*COSLAT)**2+SINLAT**2)                  CNVRT032
      SINTH = SQRT(1.-COSTH**2)                                         CNVRT034
      RGEOID = A / SQRT(1.+EP2*COSTH**2)                                CNVRT036
      X = RGEOID*SINTH + ALT*COSLAT                                     CNVRT038
      Y = RGEOID*COSTH + ALT*SINLAT                                     CNVRT040
      RKM = SQRT(X*X+Y*Y)                                               CNVRT042
      GCLAT = RAD * ATAN(Y/X)                                           CNVRT044
      RETURN                                                            CNVRT046
    2 RER=RKM/A                                                         CNVRT048
C  SEE ASTRON. J. VOL.66 P.15, 1961, FOR FORMULAS BELOW.                CNVRT050
      A2=((-1.4127348E-8/RER+.94339131E-8)/RER+.33523288E-2)/RER        CNVRT052
      A4=(((-1.2545063E-10/RER+.11760996E-9)/RER+.11238084E-4)/RER      CNVRT054
     1 -.2814244E-5)/RER                                                CNVRT056
      A6=((54.939685E-9/RER-28.301730E-9)/RER+3.5435979E-9)/RER         CNVRT058
      A8=(((320.00/RER-252.00)/RER+64.00)/RER-5.00)/RER*.98008304E-12   CNVRT060
      SCL = SIN(GCLAT/RAD)                                              CNVRT062
      CCL = SQRT(1.-SCL*SCL)                                            CNVRT064
      S2CL=2.*SCL*CCL                                                   CNVRT066
      C2CL=2.*CCL*CCL-1.0                                               CNVRT068
      S4CL=2.*S2CL*C2CL                                                 CNVRT070
      C4CL=2.*C2CL*C2CL-1.0                                             CNVRT072
      S8CL=2.*S4CL*C4CL                                                 CNVRT074
      S6CL=S2CL*C4CL+C2CL*S4CL                                          CNVRT076
      DLTCL=S2CL*A2+S4CL*A4+S6CL*A6+S8CL*A8                             CNVRT078
      GDLAT=DLTCL*RAD+GCLAT                                             CNVRT080
      ALT = RKM - A/SQRT(1.+EP2*SCL*SCL)                                CNVRT082
      RETURN                                                            CNVRT084
      END                                                               CNVRT086
```

Following are input data cards for the two LINTRA test runs:

```
  1     1965.0     1      1
 45.00       -90.00       0.0     300.0      1.0         0.     TEST 1


  1     1965.0     0      1
 75.00         0.00       0.0     300.0      1.0         0.     TEST RUN
 45.00       -90.00       0.0     300.0      1.0         0.     TEST RUN
-45.00        90.00       0.0     300.0      1.0         0.     TEST RUN
-75.00         0.00       0.0     300.0      1.0         0.     TEST RUN
```

```
C ***  MAIN FOR INVARA USING ALLMAG AND THE COORDINATE CONVERSION
C ***  DOUBLE PRECISION DECK FOR IBM 360 MACHINES (EBCDIC, 029 PUNCH)
C ***  INPUT:
C ***            ICOORD         REFERENCE SYSTEM OF INPUT COORDINATES
C ***                           =1 GEODETIC;  =2 GEOCENTRIC.
C ***            MODEL          CHOICE OF 7 MODELS (FROM ALLMAG)
C ***            TM             TIME IN YEARS FOR DESIRED FIELD
      IMPLICIT REAL*8 (A-H,O-Z)
      DATA RAD/57.2957795/
    1 FORMAT('0',9X,'GEOCENTRIC COORDINATES    GEODETIC COORDINATES',
     1 10X,'B',14X,'L',/,11X,'LAT    LONG    ALT',7X,'LAT    LONG',
     2 4X,'ALT',/,10X,'(DEGR) (DEGR)  (KM)',6X,'(DEGR) (DEGR)  (KM)',
     3 9X,'(GAUSS)',6X,'(EARTH RADII)')
    2 FORMAT(2I5,F10.3)
    3 FORMAT('0',7X,2F8.2,F8.1,1X,2F8.2,F8.1,2X,F12.5,F12.4)
    4 FORMAT(3F10.3)
    5 FORMAT('1  MODEL',I3,/,'   TIME',F8.1,/,'   ICOORD',I3)
      READ(5,2)  ICOORD,MODEL,TM
      WRITE(6,5) MODEL,TM,ICOORD
      WRITE(6,1)
      IF(ICOORD.EQ.2) GO TO 8
    7 READ(5,4,END=99)  GDLAT,GLON,GDALT
      CALL CONVRT(1,GDLAT,GDALT,GCLAT,RKM)
      CT=DSIN(GCLAT/RAD)
      GCALT=RKM-6378.16/DSQRT(1.+.0067397*CT*CT)
      GO TO 9
    8 READ(5,4,END=99)  GCLAT,GLON,GCALT
      CT=DSIN(GCLAT/RAD)
      RKM=GCALT+6378.16/DSQRT(1.+.0067397*CT*CT)
      CALL CONVRT(2,GDLAT,GDALT,GCLAT,RKM)
    9 CALL INVARA(MODEL,TM,GCLAT,GLON,GCALT,0.01D0,BB,FL)
      WRITE(6,3)  GCLAT,GLON,GCALT,GDLAT,GLON,GDALT,BB,FL
      GO TO (7,8),ICOORD
   99 STOP
      END
    2    1   1965.0
    50.000     60.000   1000.000
    30.000     60.000   1000.000
    10.000     60.000   1000.000
   -10.000     60.000   1000.000
   -30.000     60.000   1000.000
   -50.000     60.000   1000.000
    50.000    160.000   1000.000
    30.000    160.000   1000.000
    10.000    160.000   1000.000
   -10.000    160.000   1000.000
   -30.000    160.000   1000.000
   -50.000    160.000   1000.000
    50.000    260.000   1000.000
    30.000    260.000   1000.000
    10.000    260.000   1000.000
   -10.000    260.000   1000.000
   -30.000    260.000   1000.000
   -50.000    260.000   1000.000
    50.000    360.000   1000.000
    30.000    360.000   1000.000
   -10.000    360.000   1000.000
   -30.000    360.000   1000.000
   -50.000    360.000   1000.000
    10.000    360.000   1000.000
```

Input data used in INVARA test run, chosen to be compatible with Table II-2 in Hassitt & McIlwain (1967)

OUTPUT FROM STANDARD CALLING ROUTINE FOR GDALMG

MODEL	TIME	LAT	LONG	ALT	X	Y	Z	F	H	DEC	INC
MODEL USED IS NUMBER 1 HENDRICKS&CAIN 99-TERM GSFC 9/65 FOR TM = 1965.000											
1	1965.	-30.	-90.	100.	0.23810	0.06764	-0.16808	0.29919	0.24752	15.86	-34.18
1	1965.	-30.	90.	100.	0.19959	-0.06856	-0.45810	0.50437	0.21104	-18.96	-65.27
1	1965.	60.	-90.	100.	0.05993	-0.00630	0.57745	0.58059	0.06026	-6.01	84.04
1	1965.	60.	90.	100.	0.12668	0.02115	0.56277	0.57724	0.12843	9.48	77.14
MODEL USED IS NUMBER 1 HENDRICKS&CAIN 99-TERM GSFC 9/65 FOR TM = 1970.000											
1	1970.	-30.	-90.	100.	0.23523	0.06664	-0.16585	0.29543	0.24448	15.82	-34.15
1	1970.	-30.	90.	100.	0.19885	-0.06870	-0.46040	0.50619	0.21038	-19.06	-65.44
1	1970.	60.	-90.	100.	0.06146	-0.00600	0.57795	0.58124	0.06176	-5.57	83.90
1	1970.	60.	90.	100.	0.12698	0.02062	0.56456	0.57903	0.12864	9.22	77.16
MODEL USED IS NUMBER 2 CAIN ET.AL. 120-TERM GSFC 12/66 FOR TM = 1965.000											
2	1965.	-30.	-90.	100.	0.23823	0.06681	-0.16840	0.29929	0.24742	15.67	-34.24
2	1965.	-30.	90.	100.	0.20058	-0.06847	-0.45654	0.50334	0.21194	-18.85	-65.10
2	1965.	60.	-90.	100.	0.06005	-0.00627	0.57762	0.58077	0.06038	-5.96	84.03
2	1965.	60.	90.	100.	0.12716	0.01965	0.56235	0.57688	0.12867	8.78	77.11
MODEL USED IS NUMBER 2 CAIN ET.AL. 120-TERM GSFC 12/66 FOR TM = 1970.000											
2	1970.	-30.	-90.	100.	0.23521	0.06517	-0.16674	0.29559	0.24407	15.49	-34.34
2	1970.	-30.	90.	100.	0.20194	-0.06809	-0.45721	0.50444	0.21311	-18.63	-65.01
2	1970.	60.	-90.	100.	0.06205	-0.00579	0.57831	0.58166	0.06232	-5.33	83.85
2	1970.	60.	90.	100.	0.12795	0.01917	0.56524	0.57986	0.12938	8.52	77.11
MODEL USED IS NUMBER 3 CAIN&LANGEL 143-TERM POGO 10/68 FOR TM = 1965.000											
3	1965.	-30.	-90.	100.	0.23957	0.06703	-0.16721	0.29975	0.24877	15.63	-33.91
3	1965.	-30.	90.	100.	0.20044	-0.06840	-0.45674	0.50346	0.21179	-18.84	-65.12
3	1965.	60.	-90.	100.	0.05991	-0.00639	0.57780	0.58093	0.06025	-6.09	84.05
3	1965.	60.	90.	100.	0.12700	0.01963	0.56318	0.57766	0.12850	8.79	77.15
MODEL USED IS NUMBER 3 CAIN&LANGEL 143-TERM POGO 10/68 FOR TM = 1970.000											
3	1970.	-30.	-90.	100.	0.23700	0.06798	-0.16310	0.29562	0.24655	16.00	-33.49
3	1970.	-30.	90.	100.	0.19989	-0.06857	-0.45668	0.50321	0.21132	-18.93	-65.17
3	1970.	60.	-90.	100.	0.06154	-0.00575	0.57938	0.58267	0.06181	-5.33	83.91
3	1970.	60.	90.	100.	0.12860	0.01883	0.56270	0.57751	0.12997	8.33	76.99
MODEL USED IS NUMBER 4 CAIN&SWEENEY 120-TERM POGO 8/69 FOR TM = 1965.000											
4	1965.	-30.	-90.	100.	0.23954	0.06687	-0.16707	0.29960	0.24870	15.60	-33.89
4	1965.	-30.	90.	100.	0.20046	-0.06802	-0.45679	0.50346	0.21168	-18.74	-65.14
4	1965.	60.	-90.	100.	0.05987	-0.00635	0.57778	0.58091	0.06021	-6.05	84.05
4	1965.	60.	90.	100.	0.12692	0.01966	0.56312	0.57759	0.12844	8.80	77.15
MODEL USED IS NUMBER 4 CAIN&SWEENEY 120-TERM POGO 8/69 FOR TM = 1970.000											
4	1970.	-30.	-90.	100.	0.23596	0.06464	-0.16580	0.29555	0.24466	15.32	-34.13
4	1970.	-30.	90.	100.	0.20022	-0.06888	-0.45658	0.50329	0.21174	-18.98	-65.12
4	1970.	60.	-90.	100.	0.06144	-0.00616	0.57940	0.58269	0.06175	-5.73	83.92
4	1970.	60.	90.	100.	0.12833	0.01870	0.56263	0.57738	0.12969	8.29	77.02
MODEL USED IS NUMBER 5 IGRF 1965.0 80-TERM 10/68 FOR TM = 1965.000											
5	1965.	-30.	-90.	100.	0.23816	0.06658	-0.16682	0.29830	0.24730	15.62	-34.00
5	1965.	-30.	90.	100.	0.20078	-0.06798	-0.45695	0.50372	0.21198	-18.71	-65.11
5	1965.	60.	-90.	100.	0.05967	-0.00574	0.57735	0.58045	0.05995	-5.50	84.07
5	1965.	60.	90.	100.	0.12650	0.01888	0.56304	0.57739	0.12790	8.49	77.20
MODEL USED IS NUMBER 5 IGRF 1965.0 80-TERM 10/68 FOR TM = 1970.000											
5	1970.	-30.	-90.	100.	0.23596	0.06537	-0.16451	0.29498	0.24484	15.48	-33.90
5	1970.	-30.	90.	100.	0.20077	-0.06783	-0.45890	0.50547	0.21192	-18.67	-65.21
5	1970.	60.	-90.	100.	0.06126	-0.00540	0.57805	0.58132	0.06150	-5.04	83.93
5	1970.	60.	90.	100.	0.12723	0.01825	0.56485	0.57929	0.12853	8.16	77.18
MODEL USED IS NUMBER 6 LEATON MALIN EVANS 80-TERM 1965 FOR TM = 1965.000											
6	1965.	-30.	-90.	100.	0.24028	0.06833	-0.16703	0.30050	0.24980	15.87	-33.77
6	1965.	-30.	90.	100.	0.20050	-0.06946	-0.45780	0.50459	0.21219	-19.11	-65.13
6	1965.	60.	-90.	100.	0.05998	-0.00619	0.57939	0.58251	0.06030	-5.89	84.06
6	1965.	60.	90.	100.	0.12554	0.01928	0.56330	0.57744	0.12701	8.73	77.29
MODEL USED IS NUMBER 6 LEATON MALIN EVANS 80-TERM 1965 FOR TM = 1970.000											
6	1970.	-30.	-90.	100.	0.23841	0.06697	-0.16406	0.29706	0.24764	15.69	-33.52
6	1970.	-30.	90.	100.	0.19879	-0.06965	-0.46038	0.50628	0.21064	-19.31	-65.41
6	1970.	60.	-90.	100.	0.06155	-0.00593	0.58080	0.58408	0.06183	-5.51	83.92
6	1970.	60.	90.	100.	0.12651	0.01856	0.56469	0.57899	0.12786	8.34	77.24
MODEL USED IS NUMBER 7 HURWITZ US C&GS 168-TERM 1970 FOR TM = 1965.000											
7	1965.	-30.	-90.	100.	0.23904	0.06707	-0.16777	0.29965	0.24828	15.67	-34.05
7	1965.	-30.	90.	100.	0.19948	-0.06860	-0.45625	0.50266	0.21094	-18.98	-65.19
7	1965.	60.	-90.	100.	0.06025	-0.00617	0.57719	0.58036	0.06057	-5.85	84.01
7	1965.	60.	90.	100.	0.12699	0.01995	0.56219	0.57670	0.12855	8.93	77.12
MODEL USED IS NUMBER 7 HURWITZ US C&GS 168-TERM 1970 FOR TM = 1970.000											
7	1970.	-30.	-90.	100.	0.23630	0.06532	-0.16498	0.29550	0.24516	15.45	-33.94
7	1970.	-30.	90.	100.	0.19896	-0.06848	-0.45681	0.50294	0.21042	-18.99	-65.27
7	1970.	60.	-90.	100.	0.06184	-0.00597	0.57796	0.58129	0.06213	-5.51	83.86
7	1970.	60.	90.	100.	0.12816	0.01953	0.56247	0.57721	0.12964	8.66	77.02

MODEL	1
TIME	1965.00
PRINT	1
COORD	1

OUTPUT FROM LINTRA TEST RUN #1 (IPRINT = 1)

	GEOCENTRIC COORDINATES			GEODETIC COORDINATES			STEPSIZE/ARCLENGTH	DIR	HALT	LABEL
	LAT (DEGR)	LONG (DEGR)	RKM (KM)	LAT (DEGR)	LONG (DEGR)	ALT (KM)	DS/ARC (KM)			
ORIGIN	44.81	-90.00	6367.5	45.00	-90.00	0.0	811.	1.	0.	TEST 1

MODEL USED IS NUMBER 1 HENDRICKS&CAIN 99-TERM GSFC 9/65 FOR TM = 1965.000

	STEP		LAT	LON	RKM	ALT	BR	BT	BP	B
OLD COORDINATES FOR STEP#	1	**	44.808	-90.000	6368.	-0.	-0.57342	-0.15686	0.00830	0.59455
OLD COORDINATES FOR STEP#	2	**	44.808	-90.000	6368.	-1.	-0.38375	-0.12143	0.00732	0.40257
OLD COORDINATES FOR STEP#	3	**	44.808	-90.000	6368.	-1.	-0.38448	-0.12173	0.00736	0.40335
OLD COORDINATES FOR STEP#	4	**	42.865	-90.153	7145.	777.	-0.38448	-0.12173	0.00736	0.40335
OLD COORDINATES FOR STEP#	5	**	42.865	-90.153	7145.	776.	-0.27011	-0.09618	0.00616	0.28679
OLD COORDINATES FOR STEP#	6	**	40.897	-90.318	7913.	1544.	-0.27016	-0.09614	0.00615	0.28682
OLD COORDINATES FOR STEP#	7	**	40.897	-90.318	7913.	1543.	-0.19673	-0.07728	0.00510	0.21142
OLD COORDINATES FOR STEP#	8	**	38.934	-90.484	8672.	2302.	-0.19671	-0.07729	0.00510	0.21141
OLD COORDINATES FOR STEP#	9	**	36.980	-90.652	9421.	3051.	-0.14729	-0.06319	0.00427	0.16033
OLD COORDINATES FOR STEP#	10	**	35.043	-90.816	10161.	3790.	-0.11281	-0.05247	0.00362	0.12447
OLD COORDINATES FOR STEP#	11	**	33.124	-90.978	10891.	4519.	-0.08803	-0.04417	0.00311	0.09854
OLD COORDINATES FOR STEP#	12	**	31.218	-91.138	11609.	5237.	-0.06977	-0.03766	0.00270	0.07932
OLD COORDINATES FOR STEP#	13	**	29.323	-91.297	12316.	5943.	-0.05602	-0.03247	0.00237	0.06479
OLD COORDINATES FOR STEP#	14	**	27.437	-91.455	13011.	6637.	-0.04549	-0.02828	0.00210	0.05760
OLD COORDINATES FOR STEP#	15	**	25.555	-91.613	13692.	7318.	-0.03728	-0.02487	0.00188	0.04685
OLD COORDINATES FOR STEP#	16	**	23.674	-91.770	14358.	7983.	-0.03080	-0.02206	0.00170	0.03792
OLD COORDINATES FOR STEP#	17	**	21.791	-91.929	15008.	8633.	-0.02562	-0.01972	0.00154	0.03236
OLD COORDINATES FOR STEP#	18	**	19.901	-92.068	15641.	9265.	-0.02142	-0.01777	0.00141	0.02786
OLD COORDINATES FOR STEP#	19	**	18.003	-92.249	16254.	9878.	-0.01799	-0.01612	0.00130	0.02419
OLD COORDINATES FOR STEP#	20	**	16.092	-92.411	16846.	10469.	-0.01516	-0.01472	0.00121	0.02116
OLD COORDINATES FOR STEP#	21	**	14.166	-92.576	17414.	11038.	-0.01279	-0.01353	0.00113	0.01866
OLD COORDINATES FOR STEP#	22	**	12.222	-92.743	17957.	11580.	-0.01081	-0.01252	0.00106	0.01657
OLD COORDINATES FOR STEP#	23	**	10.257	-92.914	18471.	12093.	-0.00912	-0.01165	0.00100	0.01483
OLD COORDINATES FOR STEP#	24	**	8.270	-93.088	18953.	12575.	-0.00768	-0.01091	0.00095	0.01338
OLD COORDINATES FOR STEP#	25	**	6.258	-93.267	19400.	13022.	-0.00643	-0.01029	0.00091	0.01216
OLD COORDINATES FOR STEP#	26	**	4.221	-93.450	19809.	13431.	-0.00534	-0.00975	0.00088	0.01116
OLD COORDINATES FOR STEP#	27	**	2.158	-93.639	20175.	13797.	-0.00438	-0.00931	0.00086	0.01032
OLD COORDINATES FOR STEP#	28	**	0.070	-93.834	20496.	14118.	-0.00352	-0.00894	0.00084	0.00964
OLD COORDINATES FOR STEP#	29	**	-2.041	-94.034	20767.	14388.	-0.00275	-0.00864	0.00083	0.00911
OLD COORDINATES FOR STEP#	30	**	-4.174	-94.242	20984.	14606.	-0.00203	-0.00841	0.00083	0.00869
OLD COORDINATES FOR STEP#	31	**	-6.323	-94.457	21145.	14767.	-0.00136	-0.00824	0.00083	0.00840
OLD COORDINATES FOR STEP#	32	**	-8.485	-94.679	21247.	14869.	-0.00073	-0.00814	0.00084	0.00821
OLD COORDINATES FOR STEP#	33	**	-10.653	-94.909	21288.	14910.	-0.00011	-0.00809	0.00086	0.00814
OLD COORDINATES FOR STEP#	34	**	-12.822	-95.147	21268.	14891.	0.00051	-0.00810	0.00088	0.00817
OLD COORDINATES FOR STEP#	35	**	-14.985	-95.394	21187.	14810.	0.00114	-0.00817	0.00092	0.00830
OLD COORDINATES FOR STEP#	36	**	-17.136	-95.650	21046.	14670.	0.00179	-0.00830	0.00096	0.00854
OLD COORDINATES FOR STEP#	37	**	-19.270	-95.916	20848.	14473.	0.00248	-0.00849	0.00102	0.00890
OLD COORDINATES FOR STEP#	38	**	-21.383	-96.192	20596.	14221.	0.00322	-0.00874	0.00109	0.00938
OLD COORDINATES FOR STEP#	39	**	-23.473	-96.480	20293.	13918.	0.00403	-0.00906	0.00117	0.00998
OLD COORDINATES FOR STEP#	40	**	-25.536	-96.779	19943.	13569.	0.00493	-0.00945	0.00127	0.01074
OLD COORDINATES FOR STEP#	41	**	-27.572	-97.093	19549.	13176.	0.00595	-0.00992	0.00140	0.01165
OLD COORDINATES FOR STEP#	42	**	-29.582	-97.422	19116.	12743.	0.00711	-0.01047	0.00154	0.01275
OLD COORDINATES FOR STEP#	43	**	-31.565	-97.769	18647.	12275.	0.00843	-0.01113	0.00172	0.01407
OLD COORDINATES FOR STEP#	44	**	-33.523	-98.137	18145.	11774.	0.00998	-0.01189	0.00193	0.01564
OLD COORDINATES FOR STEP#	45	**	-35.458	-98.527	17614.	11243.	0.01178	-0.01279	0.00218	0.01752
OLD COORDINATES FOR STEP#	46	**	-37.373	-98.945	17056.	10686.	0.01391	-0.01383	0.00250	0.01977
OLD COORDINATES FOR STEP#	47	**	-39.269	-99.394	16474.	10105.	0.01644	-0.01505	0.00288	0.02248
OLD COORDINATES FOR STEP#	48	**	-41.149	-99.880	15871.	9502.	0.01949	-0.01648	0.00336	0.02575
OLD COORDINATES FOR STEP#	49	**	-43.017	-100.409	15248.	8879.	0.02319	-0.01817	0.00395	0.02972
OLD COORDINATES FOR STEP#	50	**	-44.875	-130.990	14607.	8239.	0.02771	-0.02017	0.00471	0.03459
OLD COORDINATES FOR STEP#	51	**	-46.726	-101.633	13949.	7583.	0.03331	-0.02255	0.00567	0.04062
OLD COORDINATES FOR STEP#	52	**	-48.572	-102.352	13278.	6911.	0.04032	-0.02540	0.00694	0.04815
OLD COORDINATES FOR STEP#	53	**	-50.417	-103.162	12592.	6227.	0.04920	-0.02886	0.00860	0.05769
OLD COORDINATES FOR STEP#	54	**	-52.264	-104.086	11895.	5530.	0.06064	-0.03309	0.01085	0.06993
OLD COORDINATES FOR STEP#	55	**	-54.114	-105.152	11187.	4823.	0.07560	-0.03831	0.01395	0.08589
OLD COORDINATES FOR STEP#	56	**	-55.968	-106.399	10468.	4105.	0.09555	-0.04484	0.01830	0.10712
OLD COORDINATES FOR STEP#	57	**	-57.828	-107.878	9741.	3378.	0.12275	-0.05311	0.02461	0.13600
OLD COORDINATES FOR STEP#	58	**	-59.692	-109.663	9005.	2643.	0.16088	-0.06373	0.03400	0.17635
OLD COORDINATES FOR STEP#	59	**	-61.555	-111.853	8262.	1900.	0.21611	-0.07753	0.04849	0.23466
OLD COORDINATES FOR STEP#	60	**	-63.404	-114.587	7512.	1151.	0.29962	-0.09570	0.07166	0.32259
OLD COORDINATES FOR STEP#	61	**	-65.216	-118.053	6756.	396.	0.43309	-0.11978	0.11018	0.46266

INTRSCT	-66.13	-120.24	6360.3	-66.27	-120.24	0.0	45819.			

MODEL	1
TIME	1965.00
PRINT	0
COORD	1

OUTPUT FROM LINTRA TEST RUN #2 (IPRINT = 0)

	GEOCENTRIC COORDINATES			GEODETIC COORDINATES			STEPSIZE/ARCLENGTH	DIR	HALT	LABEL
	LAT (DEGR)	LONG (DEGR)	RKM (KM)	LAT (DEGR)	LONG (DEGR)	ALT (KM)	DS/ARC (KM)			
ORIGIN	74.90	0.0	6358.2	75.00	0.0	0.0	3000.	1.	0.	TEST RUN

MODEL USED IS NUMBER 1 HENDRICKS&CAIN 99-TERM GSFC 9/65 FOR TM = 1965.000

INTRSCT	-67.89	73.66	6359.8	-68.02	73.66	0.0	201132.			
ORIGIN	44.81	-90.00	6367.5	45.00	-90.00	0.0	811.	1.	0.	TEST RUN
INTRSCT	-66.13	-120.24	6360.3	-66.27	-120.24	0.0	45819.			
ORIGIN	-44.81	90.00	6367.5	-45.00	90.00	0.0	811.	1.	0.	TEST RUN
INTRSCT	62.36	75.65	6361.4	62.52	75.65	0.0	46710.			
ORIGIN	-74.90	0.0	6358.2	-75.00	0.0	0.0	2364.	1.	0.	TEST RUN
INTRSCT	55.69	-45.58	6363.5	55.87	-45.58	0.0	73649.			

MODEL 1
TIME 1965.0
ICOORD 2

OUTPUT FROM INVARA TEST RUN

GEOCENTRIC COORDINATES LAT (DEGR)	LONG (DEGR)	ALT (KM)	GEODETIC COORDINATES LAT (DEGR)	LONG (DEGR)	ALT (KM)	B* (GAUSS)	L* (EARTH RADII)
MODEL USED IS NUMBER 1 HENDRICKS&CAIN 99-TERM GSFC 9/65 FOR TM = 1965.000							
50.00	60.00	1000.0	50.16	60.00	1000.0	0.34101	2.2417
30.00	60.00	1000.0	30.14	60.00	1000.0	0.28446	1.3330
10.00	60.00	1000.0	10.06	60.00	1000.0	0.23211	1.1092
-10.00	60.00	1000.0	-10.06	60.00	1000.0	0.23609	1.2581
-30.00	60.00	1000.0	-30.14	60.00	1000.0	0.26279	1.9259
-50.00	60.00	1000.0	-50.16	60.00	1000.0	0.29988	3.9519
50.00	160.00	1000.0	50.16	160.00	1000.0	0.32219	2.1171
30.00	160.00	1000.0	30.14	160.00	1000.0	0.25390	1.3242
10.00	160.00	1000.0	10.06	160.00	1000.0	0.22232	1.1209
-10.00	160.00	1000.0	-10.06	160.00	1000.0	0.26375	1.2318
-30.00	160.00	1000.0	-30.14	160.00	1000.0	0.34381	1.8405
-50.00	160.00	1000.0	-50.16	160.00	1000.0	0.40628	4.3908
50.00	260.00	1000.0	50.16	260.00	1000.0	0.37821	4.6888
30.00	260.00	1000.0	30.14	260.00	1000.0	0.32013	1.9539
10.00	260.00	1000.0	10.06	260.00	1000.0	0.24044	1.2910
-10.00	260.00	1000.0	-10.06	260.00	1000.0	0.19753	1.1643
-30.00	260.00	1000.0	-30.14	260.00	1000.0	0.22004	1.3276
-50.00	260.00	1000.0	-50.16	260.00	1000.0	0.27878	1.9094
50.00	360.00	1000.0	50.16	360.00	1000.0	0.31112	2.6404
30.00	360.00	1000.0	30.14	360.00	1000.0	0.25265	1.4280
10.00	360.00	1000.0	10.06	360.00	1000.0	0.19930	1.1712
-10.00	360.00	1000.0	-10.06	360.00	1000.0	0.18892	1.2951
-30.00	360.00	1000.0	-30.14	360.00	1000.0	0.19635	1.7096
-50.00	360.00	1000.0	-50.16	360.00	1000.0	0.22230	2.5446

*Compare these values of B and L with Table II-2 in Hassitt and McIlwain (1967)